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Effects of Environmental Conditions on Manual Actions for Flood Protection and Mitigation

Identifying Conditions, Characterizing Actions and Assessing Impacts

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Effects of Environmental Conditions on Manual Actions for Flood Protection and Mitigation

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) is carrying out a Probabilistic Flood Hazard Assessment Research Program to enhance NRC's risk-informed and performance-based regulatory approach to external flood hazard assessment. One of NRC's initiatives is to better understand the actions that nuclear power plant (NPP) licensees have planned to take outside of the main control room to prepare for, protect against, and mitigate the effects of external flooding events. The Pacific Northwest National Laboratory (PNNL) conducted a comprehensive review of research literature describing how the environmental conditions (ECs) associated with flooding events might affect performance of flood protection and mitigation actions. To support and inform the literature review, this report identifies and characterizes the ECs associated with flooding events; these conditions include heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning. Based on a review of NRC staff assessments, flooding walkdown reports at 60 NPP sites, individual NPPs' procedures (e.g., Abnormal Operating Procedures) that were available, and available descriptions of some activities related to diverse and flexible coping strategies, or FLEX, the report identifies and characterizes a set of manual actions (MAs). These example MAs would be performed at and around NPP sites (outside the main control room) in preparation for or in response to a flooding event.

This report provides an approach for decomposing the MAs into simpler units—tasks, subtasks, specific actions and performance demands—to facilitate assessment of EC impacts consistent with approaches in human performance research literature. The review of the research literature summarizes the state of knowledge concerning the effects of the ECs in terms of their mechanisms of action, effects on performance, and potential mitigation measures. Based on this review, the report presents a typology of performance demands that includes detecting and noticing, understanding, decision-making, action, and teamwork that provides a basis for applying research findings to estimate performance impacts. The report presents a conceptual framework that illustrates the relationships among ECs, MAs, and performance. The impact assessment approach is illustrated using a proof-of-concept method for an example MA. Based on the findings of the research literature review and the conceptual framework demonstrated for impact assessment, opportunities for future research are described.

This work is presented in two volume. Volume 1 describes the flood mitigation actions, a typology of performance demands, a conceptual framework with a proof of concept example and a summary of the review of literature of the impacts of environmental conditions on human performance. Volume 2 provides the complete literature review of environmental conditions on human performance, with a separate detailed chapter for each of the identified environmental conditions identified as impacting flood mitigation and performance actions.

FOREWORD

The key research question addressed in this report is what and how can existing human performance literature be used to inform the impact of environmental conditions on flood protection and mitigation procedures conducted in preparation for or during flooding events at nuclear power plants? This report was developed to provide insight into the actions that nuclear power plant licensees have planned to take to prepare for and mitigate the effects of external flooding events. This goal was undertaken as a part of the Probabilistic Flood Hazard Assessment Research program to enhance the NRC's risk-informed and performance-based approach to external flood hazard assessment.

Lessons learned from flood walkdowns conducted in response to the Near Term Task Force Recommendations following the earthquake at the Fukushima Dai-ichi facility demonstrated that environmental conditions can influence human performance and human error probabilities, especially for outdoor manual actions during flooding, and may degrade or completely preclude an individual's capability to perform the necessary actions. The degradation in performance can be measured by the (usually) additional time it may take to complete an action or by the (usually) increased probabilities of making an error. In this report, the primary focus is on the first measure (i.e., increase in task performance time); however, the conceptual framework could also be extended to support the estimation of increases in error rates and error probabilities.

This report presents a conceptual approach to assessment of manual actions performed in response to external flooding and the human performance literature findings to connect the diverse information base. The report does not present a complete method for site-specific performance impact assessment and stops well short of developing a Human Reliability Analysis (HRA) method. However, the human performance literature review results may be useful in developing such a method.

The objectives of this work were to:

1. identify and characterize typical flood protection and migration actions, referred to as manual actions,
2. review, update and synthesize the important environmental conditions that affect human performance of the flood manual actions,
3. develop a framework in which to assess the impact of the environmental conditions which fits the needs for flood manual actions and the environmental conditions likely to be present,
4. summarize the existing human performance literature within the example framework, and
5. provide a simple proof-of-concept example of the approach.

Volume 1 of this report includes objectives 1-5, while Volume 2 thoroughly documents the review of existing human performance literature that relates to environmental conditions.

The key findings from this research are:

- A set of manual actions associated with flood protection and mitigation procedures were identified from a variety of sources including plant walk downs, procedures and FLEX strategies.
- Environmental conditions associated with flooding events were identified:
  - heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning
- An approach for decomposing the flood manual actions into simpler units—tasks, subtasks, specific actions and performance demands—to facilitate assessment of environmental conditions impacts consistent with approaches in human performance research literature was developed as a basis for applying research findings to estimate performance impacts.
  - Performance demands: detecting and noticing, understanding, decision-making, action, and teamwork
- A review of research literature provided the information to summarize the state of knowledge concerning the effects of the environmental conditions in terms of their mechanisms of action, effects on performance, and potential mitigation measures.
- Based on this review, a conceptual framework that illustrates the relationships among environmental conditions, flood manual actions, and performance demands was presented
  - The impact assessment approach was illustrated using a proof-of-concept method for an example flood manual action
  - A full assessment would require site specific information and likely a method of expert elicitation to apply impact factors to specific actions
- The extension of this impact assessment approach to generalized actions that could be assessed for common flood manual actions and then applied for different site-specific conditions was discussed.
  - An example assessment using IMPRINT (a task analysis software) was conducted which allowed assessment of impacts of multiple environmental conditions, impacts on estimated time, error rates, and uncertainty.
  - Opportunities for future research to fill information gaps, reduce the limitations of the conceptual framework and other steps to a full analysis were discussed.

This report identifies flood protection and mitigation actions at nuclear power plants, environmental conditions that affect the performance of those actions, and set of performance demands that can be used within the presented conceptual framework as a basis for applying research literature findings to estimate performance impacts. The utility of the conceptual framework and review information is demonstrated in a simple proof of concept example and a more complex site-specific task analysis training demonstration. These results can be used to inform development of an HRA method or provide insights on the impacts of human performance on flood protection and mitigation procedures.

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) is conducting a Probabilistic Flood Hazard Assessment (PFHA) Research Program that is a set of research projects and tasks that the Office of Nuclear Regulatory Research (RES) is implementing to enhance NRC's risk-informed and performance-based regulatory approach to external flood hazard assessment. The PFHA plan is designed to support development of regulatory tools (e.g., regulatory guidance, standard review plans) for permitting new nuclear sites, licensing activities for operating and new nuclear facilities, and oversight activities (e.g., inspections, Significance Determination Process (SDP) of operating facilities. As a part of the PFHA plan and Fukushima Near-Term Task Force (NTTF) activities, the NRC undertook several initiatives to ensure that actions taken outside the main control room required for flood protection and mitigation are both feasible and reliable. One of those initiatives was to better understand the actions that nuclear power plant (NPP) licensees have planned to take outside the main control room to prepare for, protect against, and mitigate the effects of such external flooding events, including lessons learned from implementation of NTTF recommendations.

The purpose of this report is to review human performance research literature and compile information pertinent to assessing the impacts of environmental conditions (ECs, e.g. heat or wind) accompanying external floods on the performance of human actions. These actions, specified in flood protection and mitigation procedures, are referred to in this report as manual actions (MAs). A primary objective is to provide a conceptual framework that makes this information useful. This project updates and expands the previous review of the research literature in NUREG/CR-5680 (Echeverria et al., 1994). The scope of this project stops short of characterizing the MAs or ECs at a particular plant or developing and testing a method for applying the research results to estimate the impacts on the performance of specific MAs. Therefore, the project scope does not extend to (1) consideration of the site-specific context that determines the parameters of the MAs and (2) addressing how variations in individual attributes (e.g., knowledge, training, preparedness, organizational role, and fitness) might affect performance. Based on the scope, the assumptions were that (1) the flood protection and mitigation procedures are established, appropriate, and feasible; (2) the individuals performing the MAs are trained and have necessary equipment and access; (3) the staffing levels and crew composition are adequate; and (4) the individuals performing the MAs would be fit for duty and not fatigued. Consideration of other factors known to influence performance were excluded; for example, individual characteristics (e.g., gender, age, emotions, innate ability, and physical condition), the availability of materials and equipment, the quality of plant procedures, or training. These assumptions and exclusions focused the work on describing the effects of ECs on performance of MAs with reference to a baseline metric (i.e., performance time, error rate, or probability of failure for completing an MA by a fit, knowledgeable, and adequately staffed crew under ECs that do not impact performance). The impact of ECs is expressed as an increase in performance time, error rate, or probability of failure for completing an MA.

To inform and support the conceptual framework, the flood hazard was characterized across U.S. NPP sites. Eleven environmental conditions[1] that may accompany various flood causing mechanisms were identified, considering the geographical diversity of the locations of NPPs in the U.S. MAs were characterized using (1) an analysis of the NRC staff assessments of NPP

[1] The eleven identified environmental conditions are heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning.

flooding walkdown reports, (2) a review of five available individual plant procedures, and (3) a description of diverse and flexible coping strategies, or FLEX procedures. The research team decomposed the MAs into their simpler elements (e.g., tasks, subtasks, and specific actions) using a task analysis approach.

To characterize human physiological and cognitive capabilities that are required for successful completion of specific actions, and in turn, higher-level subtasks, tasks, and MAs, human performance taxonomies were reviewed. Combining three such human performance taxonomies - the performance abilities identified in NUREG/CR-5680 Volume 2, the taxons used by O'Brien et al. (1992), and the macrocognitive functions identified in NUREG-2114 (USNRC, 2016b) - the research team developed a taxonomy of nine performance demands[2].

Environmental conditions can adversely affect human performance. These potential effects (11 ECs affecting the 9 established performance demands) are the key components of impact assessment in the conceptual framework, and result in the increase of performance time, error rate, or probability of failure for completing an MA. For example, gross motor actions such as walking can be significantly affected by impeding forces from standing and moving water, fine motor actions can be significantly affected by cold, and sustained heat exposure can affect memory and vigilance.

To establish the impact assessment approach, the research team reviewed (1) existing impact assessment methods for NPPs, (2) assessment methods use in other domains where tasks are typically less highly proceduralized and more physically demanding, and (3) existing task and human ability typologies. Based on this review, the research team concluded that adapting a task analysis framework developed by the U.S. Army Research Laboratory offered an advantageous method to relate research findings to performance impacts. The major difference between this approach and that used in some NPP human reliability analyses (HRAs) is a greater emphasis on physical actions. This was selected because flood protection and mitigation activities often involve considerable movement and exertion and an expansion of roles to include plant staff who are not licensed or field operators.

The research literature indicated that ECs' impact on human performance could be characterized though their effects on performance demands. The specific actions discussed in this report are derived from task analysis, emphasizing the performance demands they impose. For example, a specific action, "unsheltered walking 400 m from sheltered point A over flat ground to sheltered point B on Site S," involves walking, which is a gross motor action, although some detecting and noticing as well as decision-making are required. The framework links the research findings on human performance to the assessment of EC impacts on specific actions via their corresponding performance demand compositions (i.e., in the above example, the impact of prevailing ECs on walking would be estimated via the ECs' effects on gross motor action, detecting and noticing, and decision-making). The specific actions derived from MAs at a particular NPP site would contain site-specific information (i.e., the site-specific facility layout, topography, and task sequence and context). It may also be possible, for some needs, to group multiple, similar specific actions into categories, termed generalized actions that are independent of site and task contexts. This approach would provide a way to transfer

[2] The nine performance demands are: (1) detecting and noticing, (2) understanding, (3) decision-making, (4) action – fine motor, (5) action – gross motor, (6) action – other neurophysiological functions, (7) teamwork – reading and writing, (8) teamwork – oral communication, and (9) teamwork – crew interaction.

knowledge and experience gained from relatively few site-specific task analyses across NPP sites. The research team noted that performance demand profiles[3] can be used to consistently define generalized actions with wide applicability across NPP sites.

These steps to characterize flood protection and mitigation procedures, identify environmental conditions, develop a performance demand typology and an approach to assess the impact of the environmental conditions on the human performance of these action. EC effects on performance demands that have been documented in the literature were summarized and categorized into four different levels of knowledge, based on the extent and quality of the research available. The levels range from identified quantitative impact (Level 1), to quantitative thresholds (Level 2), to qualitative information (Level 3) and to an information gap (Level 4). This first volume of this report summarizes the key results from the literature review, while the second volume provides full details of the literature related to the impacts of ECs on human performance. The research team concluded there are significant research gaps in the human performance literature. Moreover, relatively modest progress has been made in quantifying the effects of ECs across the range of performance demands pertinent to manual actions since preparation of NUREG/CR-5680 (Echeverria et al., 1994). The literature search did not identify any large-scale ongoing or upcoming research programs from which major advances might be expected. Consequently, it appears likely that progress will be largely incremental in the upcoming years. Therefore, application of an impact assessment approach would need to innovatively and consistently apply the currently available knowledge. Nonetheless, these research gaps could be addressed by conducting sensitivity analyses to determine EC-performance demand combinations that most affect flood protection and mitigation MAs. Insights gained from sensitivity analyses could help reduce uncertainties about the estimation of impacts and direct future research.

[3] The performance demand profile of a specific or a generalized action is defined by the relative contributions of the different performance demands required to perform the action.

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ABBREVIATIONS AND ACRONYMS

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
ACGIH	American Conference of Governmental Industrial Hygienists
ARL	U.S. Army Research Laboratory
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BEI	Biological Exposure Indices
cd	candela
Clo	clothing thermal insulation index
cm	centimeter(s)
cm/s	centimeter(s) per second
CRI	color rendering index
dB	decibel(s)
dB(A)	A-weighted decibel
EC	environmental condition
EPA	U.S. Environmental Protection Agency
FCM	flood causing mechanism
FHWA	Federal Highway Administration
FLEX	diverse and flexible coping strategies
ft	foot(feet)
ft/s	foot(feet) per second
ft^2/s	square foot(feet) per second
FNU	Formazin Nephelometric Unit
GA	generalized action
g	gram(s) or acceleration due to gravity
g/L	gram(s) per liter
h	hour(s)
HEP	human error probability
HFE	human failure event
HRA	human reliability analysis
Hz	hertz
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IMPRINT	Improved Performance Research Integration Tool
in.	inch(es)
IOSH	Institute of Occupational Safety and Health
ISO	International Standards Organization
kCal	kilocalorie
kg/m^3	kilogram(s) per cubic meter

km	kilometer(s)
km/h	kilometer(s) per hour
km/s	kilometer(s) per second
kt	knot(s)
lb/ft^3	pound(s) per cubic foot
LED	light-emitting diodes
LIP	local intense precipitation
m	meter(s)
m^2/s	square meter(s) per second
MA	manual action
mi^2	square mile(s)
MCR	main control room
min	minute(s)
mm	millimeter(s)
mm/hr	millimeter(s) per hour
m/s	meter(s) per second
mph	mile(s) per hour
NASA	National Aeronautics and Space Administration
NIOSH	National Institute for Occupational Safety and Health
nm	nanometer(s)
N/m^2	newton(s) per square meter
NOAA	National Oceanic and Atmospheric Administration
NPP	nuclear power plant
NRC	U.S. Nuclear Regulatory Commission
NTTF	Near-Term Task Force
NTU	Nephelometric Turbidity Unit
NWS	National Weather Service
OSHA	Occupational Safety and Health Administration
PIF	performance influencing factor
PRA	probabilistic risk assessment
PSF	performance shaping factor
R2	coefficient of determination
RG	Regulatory Guide
rms	root-mean-square
rms-g	root-mean-square acceleration
s	second(s)
SA	specific action
SAVE-IT	Safety Vehicle Using Adaptive Interface Technology
SDP	Significance Determination Process

SI	International System (of units)
SPAR-H	Standardized Plant Analysis Risk-Human Reliability Analysis
SWV	safe walking velocity
THERP	Technique for Human Error-Rate Prediction
TLV	threshold limit value
USGS	U.S. Geological Survey
UV	ultraviolet
VO_2	maximum volume of oxygen
WBGT	wetbulb globe temperature

1 INTRODUCTION

1.1 Context and Purpose

The U.S. Nuclear Regulatory Commission (NRC) is conducting a Probabilistic Flood Hazard Assessment (PFHA) Research Plan which is a set of the research projects and tasks that the Office of Nuclear Regulatory Research (RES) is implementing to enhance NRC's risk-informed and performance-based regulatory approach to external flood hazard assessment (NRC 2014). The plan is designed to support development of regulatory tools (e.g., regulatory guidance, standard review plans) for permitting new nuclear sites, licensing actions of operating and new nuclear facilities, and oversight activities of operating facilities. As a part of the plan, NRC also undertook several initiatives to ensure with high confidence that actions taken outside the main control room required for flood protection and mitigation are both feasible and reliable[1], including lessons learned from implementation of the Fukushima Near Term-Task Force (NTTF) recommendations[2]. To do so, this project has several goals: (1) to gather information on the flood protection and mitigation procedures at nuclear power plants (NPPs), (2) to assemble information about environmental conditions (ECs) and their impact on performing those procedures and (3) to develop a framework to analyze the impact of the environmental conditions on performance of the flood protection and mitigation procedures. In this report, the human actions specified in flood protection and mitigation procedures are referred to as manual actions (MAs).

This report updates and expands on NUREG/CR-5680, The Impact of Environmental Conditions on Human Performance, Volumes 1 and 2, 1994, which reviewed research completed prior to the mid-1990s on the impact of ECs on human performance (Echeverria et al., 1994). The purpose of the 1994 report was to provide a source of information and technical guidance on how exposure to certain ECs could affect human performance. NUREG/CR-5680 was intended for use by NRC staff to follow up events in which environmental stressors or ECs may have been implicated in events that involved human performance.

The purpose of this report is to review human performance research literature and compile information pertinent to assessing the impacts of ECs accompanying external floods on the performance of MAs. This study also defines a conceptual framework that makes the information useful for assessing the impacts of ECs on human performance. It is intended to assist NRC staff who will review and evaluate plans for events in which exposure to ECs may impair the performance of those attempting to implement the MAs required for flood protection and mitigation. It may also provide useful information to applicants and licensees that develop and evaluate procedures requiring MAs.

[1] An action is considered feasible if an analysis has shown that it can be performed correctly within an available timeframe that avoids an undesirable outcome. A feasible action is considered reliable when it can be shown to be dependably repeatable within an available timeframe (as defined in NUREG-1852; USNRC, 2007a). However, it should be noted that NUREG-1852 is focused on deterministic criteria and those qualitative terms (feasible and reliable) are not generally used in the context of quantitative risk assessments because PRAs quantitatively consider human errors by developing and using their associated failure probabilities.

[2] On March 11, 2011, a 9.0-magnitude earthquake struck Japan and was followed by a 45-foot tsunami, resulting in extensive damage to the nuclear power reactors at the Fukushima Dai-ichi facility. The NRC developed a senior-level agency task force to conduct a methodological and systematic review of the NRC's related processes and regulations. In July 2011, that Near-term Task Force (NTTF) made recommendations based on lessons-learned including flood hazard reevaluations (2.1) and flood walkdowns (2.3).

1.2 Background

On March 12, 2012, the NRC issued a request to all power reactor licensees and holders of construction permits to reevaluate flood hazards at their sites using updated flood hazard information and present-day regulatory guidance (USNRC, 2012d). The letter requested a determination of whether the reevaluated flood hazards were bounded by the current design basis and, if not, to perform an integrated assessment of plant response to the unbounded flood hazard. The letter also requested NPP licensees conduct walkdowns of plants to include verification of the adequacy of programs, monitoring and maintenance of flood protection and an assessment of whether flood protection systems were implementable. The letter specifically mentioned confirming that the effects of elevated water levels and severe environmental conditions would not impair support functions or would not impede performing necessary actions given the weather conditions. A number of significance determination process[3] (SDP) evaluations were completed following the flood hazard walkdowns recommended by the NRC (Ferrante, 2015). Challenges encountered in performing these evaluations highlighted the need for more detailed risk evaluation and further risk-informed guidance and tools (Ferrante, 2015).

The NRC issued guidance for performing the requested integrated assessments which states that the "analysis will evaluate the total plant response to the flood hazard considering multiple and diverse capabilities such as physical barriers, temporary protective measures, and operational procedures" (USNRC, 2012d, p. 3). The guidance explains that a key part of the integrated assessment will be evaluation of MAs to ensure that those required in response to flooding events are feasible and reliable. The guidance also provides information about evaluation approaches based on human factors, engineering, and human reliability analysis (USNRC, 2012b, p. 56).

Human reliability analysis (HRA) is a systematic approach for identifying and estimating the probability of human performance failures as part of a larger probabilistic risk assessment (PRA) study. HRA and PRA are important industry and regulatory tools for assessing the risk of NPP events that result in reactor trip, including operator actions that are required to mitigate such events. For each human action on which plant safety depends, an important aspect of the HRA assessment of feasibility and reliability is consideration of the impact of multiple performance shaping factors[4] (PSFs) such as task complexity and usability of procedural instructions. Flooding events have demonstrated that ECs can be important new PSFs to consider, especially for outdoor manual actions during flooding, and may degrade or completely preclude an individual's capability to perform the necessary actions. The degradation in performance can be measured by the (usually) additional time it may take to complete an action or by the (usually) increased probabilities of making an error. In this report, the primary focus is on the first measure (i.e., increase in task performance time); however, the conceptual framework could also be extended to support the estimation of increases in error rates and error probabilities.

[3] The significance determination process (SDP) is the process used by the NRC staff to evaluate inspection findings to determine their safety significance. This involves assessing how the inspection findings affect the risk of a nuclear plant accident, either as a cause of the accident or the ability of plant safety systems or personnel to respond to the accident.

[4] PSF is defined as a factor that influences human performance and human error probabilities, including time available, stress/stressors, complexity, experience/raining, procedures, ergonomics/human-machine interface, fitness for duty, and work processes (NUREG/CR-6883, Gertman et al., 2005).

Ferrante (2015) explains that it is “fully recognized” that HRA approaches for evaluating manual actions are not well established. Nonetheless, for the purposes of performing its significance determination process at a particular plant, the NRC used an HRA model to demonstrate that the human error probabilities (HEPs) for manual actions at a particular plant are high (i.e., 0.11 to 0.43), suggesting sensitivity to ECs and other PSFs associated with flooding events. Ferrante (2015) also states, “No single HRA method exists to evaluate actions which need to be performed during potential significant challenges resulting from an extreme flood (e.g., with significant stress and mobility issues).” However, such impacts on manual actuation of equipment, implementation of flood barriers, and other MAs performed in the outdoor environment exposed to ECs must certainly be greater than the impact on actions performed indoors for which HRA methods are more established and where there are fewer complicating PSFs. Ferrante (2015) recommends the development or enhancement of existing tools for estimating human error probabilities for actions performed outside the main control room in situations that may involve extreme ECs.

This report discusses how assessment of the feasibility and reliability of MAs performed in response to external flooding would benefit from information about the impact of ECs on human performance. This report presents a conceptual framework and the human performance literature findings to connect the diverse information base. The report does not present a complete method for site-specific performance impact assessment and stops well short of developing an HRA method. However, the human performance literature review results may be useful in developing such a method, as well as to support application of HRA methods in other contexts where adverse environmental conditions are a potential concern.

The final list of environmental conditions considered in this report includes: heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning.

1.2.1 Scope and Limitations

A primary focus of this project is to update and expand the previous review of the research literature to provide the most current technical basis for assessing the impact of specified ECs on the performance of specified tasks. To inform and support this review, the research team developed an overview of the flood hazard across NPPs, an overview of flood protection and mitigation MAs across NPPs, and an overall conceptual framework. The research team also reviewed available materials to prepare a preliminary characterization of the ECs that accompany flooding events and a characterization of the flood protection and mitigation MAs that would be performed at NPPs (outside of the main control room). The human performance information can be used to inform HRA methods for determining the effects of ECs on flood protection and mitigation procedures.

The scope of this project, however, stops short of characterizing the tasks or ECs at a particular NPP or developing and testing a method for applying the research results on the impacts of ECs on the performance of specific tasks. Nonetheless, during the development of the framework, the research team found it useful to think through the analytical steps that would be needed in an impact assessment and those insights are included here. Impacts are defined as the difference in performance (measured in time, error rates, and probabilities of failure) under normal conditions (baseline) and under the prevailing ECs. The research team defined a conceptual framework that uses the human performance information for assessing the impacts of ECs on MAs. The report does not include development and description of a complete method, although a simplified example is provided to illustrate how the impact of one EC on the performance time of a task can be quantitatively estimated if detailed information is available.

The scope of this study was limited to focus on surveying the mitigation actions, reviewing literature on the impacts of environmental conditions and exploring a conceptual framework for a simple procedure. Several elements that would be needed for a complete analysis are not addressed completely in this study. These elements may not have been addressed due to limited site-specific details, lack of literature or attempts to simplify examples. Table 1.1 describes the limitations on some elements of this study and if they are addressed by the proposed framework and included in various examples.

Many expert decisions would be required to implement the elements of this framework. Information and experience from other industries or a structured method for eliciting expert judgement (e.g. Xing et al., 2015), would be ways to provide these details when there is limited operational experience or gaps in the existing human performance research literature.

1.3 Structure of Report

The results of this study are presented in two volumes: Volume 1 includes the overview of flood hazards, flood protection MAs and the environmental conditions of concern. It also describes a conceptual framework for assessing the impacts, summarizes the human performance literature and a simple proof-of-concept example. Volume 2 provides a full detailed literature review of the impacts of environmental condition on human performance as relates to flood mitigation actions.

Volume 1 begins with this introductory chapter describing the purpose and background. Chapter 2 is an overview of the flood hazards at U.S. NPPs and describes the flood causing mechanisms that can affect safe operations at NPPs based on a review of the flood causing mechanisms that could affect NPP operations. These mechanisms include local intense precipitation (LIP); precipitation and snowmelt in the upstream drainage area; breaches of dams or failure of water storage structures; storm surges and seiches; tsunamis; failures of and effects from ice jams; and geomorphic changes to river or stream channels. Environmental conditions that may occur in the general timespan of the flood causing mechanisms and subsequent flooding events are identified.

Chapter 3 focuses on characterizing the MAs performed at NPPs in response to external flooding events in order to protect the NPP from flooding impacts or to mitigate those impacts. The overview of the typical MAs and their characteristics presented in this report emerged from a review and integration of (1) an analysis of the NRC Staff Assessments of NPP flooding walkdown reports, (2) a review of five available individual plant procedures, and (3) a description of diverse and flexible coping strategies, or FLEX procedures. Actions taken or directed by plant staff outside main control rooms are referred to as manual actions (e.g., installing sump pumps and flood barriers) in this report.

Chapter 4 presents an overview of the methods available to assess the impacts of ECs on human performance. Probabilistic risk assessment and human reliability analysis approaches used in the nuclear industry and a task analysis approach in a non-nuclear setting are summarized. The chapter introduces a proposed approach to apply results from the research literature to assess impacts on the performance of MAs.

Table 1.1 Limitations of how elements that would be considered in a full analysis are addressed in this report

Elements of human performance	Examples	Addressed/ Discussed in			Included in Examples for			Out of Scope, Infor-mation Gap
		Literature Review	Conceptual Framework	Existing HRA methods	Decomposition	Simple Proof of Concept	IMPRINT Example (Appendix D)	
Variation in individual attributes	Knowledge, training, preparedness, organizational role, fitness			X				
Site specific context of MAs	Distance to equipment	X	X		X		X	X
Presence of multiple or combinations of ECs	Rain and wind, secondary ECs	X	X			X	X	
Availability of equipment or materials	Event-damaged or misplaced tools, time to put on PPE	X						X
Quality of plant procedures or training	Assumed appropriate		X					X
Measure or estimate other emergency situation factors	Fear, stress, fatigue	X						X
Detecting need for or initiating flood mitigation procedures	Poor forecast	X						X
Failure assessed by comparing baseline time to environmental condition affected time	Longer time to travel a distance due to rain	X	X	X	X	X	X	
Recovery time after failure	Replacement of lost tool from storage	X					X	
Failure assessed due to accuracy	Dropped or lost tool	X					X	
Distribution of effects randomly sampled	Monte Carlo sampling in IMPRINT	X					X	

In Chapter 5 the research team establishes a framework and approach for linking the research of the impacts of ECs on human performance to the impacts of ECS on performance of flood mitigation MAs in NPP settings. The research team evaluated the typologies and paradigms used by previous researchers and developed a taxonomy of “performance demands” to characterize the physiological and cognitive abilities that are called upon to meet task performance requirements for flood protection and mitigation procedures. Performance demands provided a basis for characterizing MAs across NPP sites.

Chapter 6 presents and applies an approach to decomposing typical MAs into more elemental actions (tasks, subtasks, and specific actions). The purpose of decomposing the MAs was to provide a clearer intersection with the human performance research literature, which is often focused on very simple actions. Examples of applying the decomposition process to selected MAs are described. This chapter also describes a process for generalizing specific actions to decouple them from the site-specific MAs where they originated. The notion here is to develop a list of generalized actions that are site-independent, but when combined with site-specific task order and facility layout information, could serve as building blocks for the assessment of the flood protection and mitigation MAs at any NPP site.

Chapter 7 describes the overall conceptual framework to assess the impacts of ECs associated with a flooding event on the performance of flood protection and mitigation MAs. The team describes the components of the framework and their interrelationships and provide a graphic representation of the components.

Chapter 8 includes identification and characterization of the primary, secondary, and likely combinations of ECs that may result from the environmental conditions that are associated with a flooding event. Particular dimensions of the environmental conditions associated with flooding events that are known to, or may be expected to, affect human performance, and that therefore may be called out separately in the research literature, are identified. Key findings from the literature regarding the impact ECs have on human performance are summarized, highlighting the nature, magnitude, and mechanisms by which ECs impact human performance.

A complete description of the process for identifying and characterizing MAs and the basis for and examples of decomposition are provided in Chapter 9 Then the application of the conceptual framework is demonstrated using an example to estimate the impact of one EC on a task, lists limitations of the proof-of-concept method, and suggests future enhancements. Chapter 10 summarizes the findings of the research, describes the anticipated near-term advances, and recommends research opportunities for future work. The next steps required to implement the conceptual framework are also described.

Appendix A presents a synthesis of MAs from the NPP licensees' Flooding Walkdown Reports and the NRC's corresponding staff assessments of the Flooding Walkdown Reports. Appendix B presents the MAs for one NPP for which a flood protection and mitigation procedure was available for review. Appendix C presents a compendium of literature reviewed during the preparation of this report. Appendix D is a description of an example assessment of impacts of environmental conditions on a manual action using Imprint Pro.

Volume II presents the full human performance research literature review organized in individual environmental conditions chapters. It also includes a summary chapter that describes knowledge advances since the publication of NUREG/CR-5680 (Echeverria et al., 1994), current state of knowledge for EC-performance demand combinations pertinent to flood protection and mitigation activities, and opportunities for future research on ECs.

2 OVERVIEW OF THE FLOOD HAZARD AND ENVIRONMENTAL CONDITIONS AFFECTING HUMAN PERFORMANCE AT NUCLEAR POWER PLANTS

U.S. nuclear power plants (NPPs) are exposed to a variety of external hazards, including floods. The U.S. Nuclear Regulatory Commission (NRC) considers external floods when licensing commercial reactors (see 10 CFR 50, 2015). In 2018 98 reactors at 59 sites Figure 2.1) were in operation in the United States (USNRC, 2018). Because of the varied geographical locations and hydrometeorological conditions at these sites, external floods at NPPs can result from various flood causing mechanisms (FCMs) and combinations of FCMs (NUREG/CR-7046, Prasad et al., 2011; NUREG-0800, Rev. 3, USNRC, 2007b).

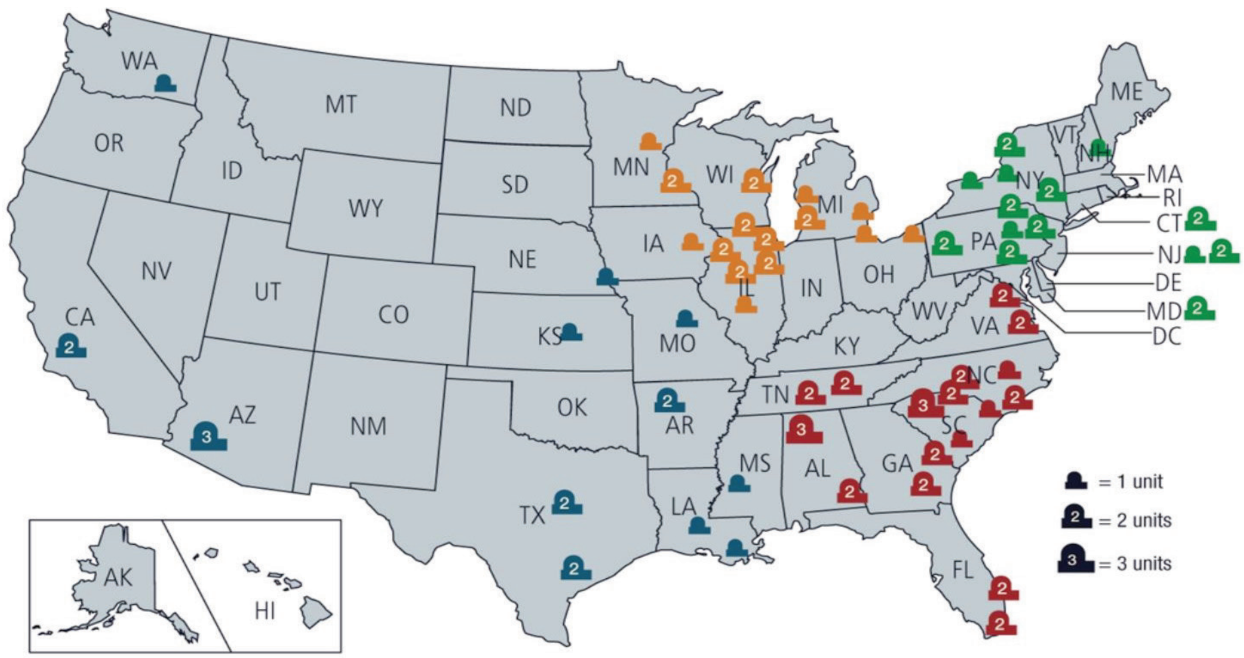

Figure 2.1 Locations of currently operating nuclear power plants (as of May 2018)

2.1 Floods of and Flood Causing Mechanisms of Interest at Nuclear Power Plants

In this report, floods of interest are those that trigger flood protection and mitigation procedures at NPPs. Because flood protection and mitigation procedures are normally triggered in anticipation of an imminent flood and because that flood could reach or exceed the severity of a design-basis flood, the research team considered floods ranging from below design basis to beyond design basis.
Individual flood causing mechanisms typically evaluated for NPP safety are summarized below:

- Local intense precipitation. A LIP event is a local (usually defined as 1 mi^2 or less in area), high intensity, precipitation event. LIP events are expected to result from intense thunderstorms, mesoscale convective systems, or from tropical or extratropical cyclones.

Local drainage features and the layout of site buildings can significantly influence the flood characteristics across an NPP site during a LIP event.

- Rivers and streams. Floods in rivers and streams near an NPP site may be caused by precipitation in the upstream drainage area. Depending on geographical location and the hydrometeorological characteristics of the drainage basin (including antecedent conditions), these floods can be generated by a heavy precipitation event, melting of a large snowpack, or a combination of the two. Other hydrometeorological or geophysical conditions that manifest due to the geographical setting of an NPP may also affect floods in rivers and streams. For example, tidal and other oceanic processes may affect floodwater surface elevations in the river or stream of interest, upstream dams may fail during a large flood, or water surface elevation in adjacent lakes or reservoirs may be high.
- Dam or water storage/conveyance structures. Floods may be generated by individual, multiple, or cascading failures of upstream dams with an accompanying flood (i.e., hydrological failures) or without (i.e., sunny day failures, seismic failures); by improper operation of a downstream dam that may cause water to back up to the NPP site; by failure of onsite or offsite water storage structures; or by failure of an adjacent water conveyance facility (e.g., a canal or a levee). A flood could also be caused by an operational or intentional large release from an upstream dam or storage structure.
- Storm surge. Storm surge is a rise in offshore water elevation caused principally by the shear force of the winds acting on the water surface. Coastal areas, including those of the Great Lakes, are exposed to storm surge. Winds are usually due to tropical or extratropical cyclones in coastal areas. Storm surge can raise water surface elevations in rivers near estuaries, and in some rivers, storm surge can affect water surface elevations some distance inland. In general, tropical cyclones also bring moderate to heavy rain, which may result in concurrent flooding both locally and in the drainage basin of a river or stream.
- Seiches. A seiche is a standing wave oscillation of the water surface in an enclosed or semi-enclosed waterbody initiated by an external cause (NUREG/CR-7046, Prasad et al., 2011). In general, the external force is a meteorological event (e.g., a rapid change in wind direction), seismic event, or tsunami. All lakes, bays, and estuaries may be subject to a seiche if the external forcing matches the fundamental frequency of oscillation of the waterbodies.
- Tsunamis. Tsunamis are a series of water waves that propagate from the point of generation toward the shore (NUREG/CR-6966, Prasad, 2009). Typically, tsunami refers to an oceanic tsunami caused by an earthquake or landslide. Oceanic tsunamis can be far-field or near-field, depending on the location of the tsunamigenic source. However, tsunamis or tsunami-like waves can also occur in inland waterbodies following landslides. These tsunami-like waves are commonly near-field phenomena. Shore areas, including those of coastal areas of the Atlantic and Pacific Oceans, the Gulf of Mexico, and the Great Lakes and those of inland lakes may be subject to tsunamis or tsunami-like waves. In December 1811 and February 1812, tsunami-like waves were reported to occur in the Mississippi River following the New Madrid earthquake (Lander et al., 2002). Following the eruption of Mount St. Helens in 1980, a tsunami-like wave was caused by debris falling into Spirit Lake (Waitt & Pierson, 1994).
- Ice effects. Prolonged cold spells can create freeze-up ice jams, while strong warm spells or heavy precipitation can cause break-up ice jams on rivers. These temporary obstructions can cause floods by either backing up water to an NPP site located upstream or by causing a flood wave to propagate downstream when the ice jam collapses

(NUREG/CR-7046, Prasad et al., 2011). Geographical location and hydrometeorological characteristics must be amenable for the formation of ice jams.

- Channel migration. Under suitable geomorphological conditions, natural channels may be subject to geomorphic changes (i.e., changes to the channel profile or position) that cause flooding of adjacent areas (NUREG/CR-7046, Prasad et al., 2011). River channel migration is the lateral motion of an alluvial river channel across its floodplain due to processes of erosion and deposition on its banks and bars. Channel diversions typically occur during large floods.

Because of the varied hydrometeorological and geoseismic processes that compose FCMs and the varied hydrometeorological and geomorphic settings of NPPs, a range of environmental conditions (ECs) could occur along with a flood. In addition, some FCMs can occur together (e.g., a hurricane that causes a storm surge influencing ambient water surface elevations in a river may also cause a riverine flood generated by precipitation from the hurricane). Typically, concurrent conditions (e.g., wind induced wave activity) are considered in combination with most individual FCMs.

2.2 Associated Environmental Conditions

Environmental conditions that could occur during a flood of interest resulting from the range of FCMs and combinations of FCMs are discussed in the following subsections. It should be noted that the environmental conditions observed at the site may not be constrained by an FCM. For example, seismic or sunny-day dam failures could have little influence on the environmental conditions at the site other than standing and moving water. For floods of hydrometeorological origin in large river basins, the storm that causes the flood may occur far from the site and have a potentially small influence on environmental conditions observed at the site. For non-hydrometeorological floods originating far from the NPP site (e.g., a tsunami), any set of meteorological conditions (e.g., air temperature, humidity, precipitation, wind, and snowpack) within the NPP site's range are possible.

2.2.1 Local Intense Precipitation

Based on a review of licensee flood reevaluation submittals, LIP is the design-basis FCM at approximately one-third of operating U.S. NPP sites; however, all NPP sites are exposed to the effects of a LIP event. LIP events are not limited to particular geographical areas, but can occur throughout the U.S. The environmental conditions of interest during a LIP flood are primarily the meteorological conditions associated with a high intensity local storm (e.g., a thunderstorm, a mesoscale convective system, or a tropical or extratropical cyclone).

A thunderstorm is generally accompanied by strong winds, rain, thunder, and lightning. Temperatures at the land surface are generally above freezing, because it is the updraft of warm air at the surface that drives the storm. However, cold air aloft can freeze moisture into hail. The National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) defines a "severe" thunderstorm as a storm having any one of these conditions: hail 1 in. or greater in diameter, wind gusts greater than 57.5 mph (50 knots), or a tornado. The NWS defines a thunderstorm as "approaching severe" if hail is 0.5 in. or greater in diameter and/or the wind is 40 mph (35 knots) or more. Thunderstorms can occur anywhere at any time of the year but are more prevalent in spring and summer throughout most of the United States (NOAA-NWS, 2014b). Thunderstorms are less common on the U.S. West Coast compared to other regions of the country.

Tropical cyclones usually originate between 5 to 30 ºN latitudes and are characterized by rainfall, a low-pressure center, strong winds, rapid rotation and a spiral arrangement of the thunderstorms that produce heavy rain. Tropical cyclones are classified in order of increasing maximum sustained wind speeds as a tropical depression (up to 38 mph), tropical storm (39 to 73 mph), and hurricane (74 mph or higher). The NWS considers June 1 through November 30 to be the official hurricane season for the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, with the peak storm activity generally occurring between mid-August and late October. Although the most intense precipitation associated with tropical cyclones tends to fall in the coastal areas extending from east Texas through Florida and up the Atlantic coast north of Maine, the storms can reach inland across the southern and eastern United States. In the southwestern United States, tropical storm remnants from the eastern Pacific Ocean or Gulf of Mexico can be responsible for intense precipitation events (NOAA-NWS, 2014c, 2015c).

The environmental conditions that could be expected with a LIP flood event would be heavy precipitation, generally in the form of rain but possibly hail, and accompanied by wind. Temperatures would generally be above freezing, and humidity would be high. Low, dark clouds and heavy precipitation could result in low ambient light during daylight hours; precipitation and wind could further reduce visibility. Precipitation, wind, and thunder would increase both ambient and occasional noise levels. Standing or moving water could occur if the local site drainage system is overwhelmed or blocked. Moving water and wind could erode, entrain, and/or deposit particles and debris. Although a LIP event is defined as local, antecedent or subsequent precipitation in nearby areas could affect the severity and persistence of most of these environmental conditions.

Threshold flood response time (i.e., the duration between notification of impending flood or inundation/ponding and the time a threshold for flood response action is reached) and response time (i.e., the duration between the time a threshold for flood response action is reached and the time the action must be completed) are typically very short, even on the order of a few minutes, for LIP events. Local ponding due to LIP can occur in depressions, causing an environmental condition of standing water, while accumulation of significant amounts of snow may also occur, though generally over a longer time.

2.2.2 Streams and Rivers

Flooding in streams and rivers (i.e., riverine flooding) could affect more NPPs than any other single FCM other than the LIP. Based on a review of information from licensee flooding reevaluation submittals, riverine flooding is, or contributes to, the design-basis flood at nearly 50 percent of NPP sites. This type of flooding can result from prolonged intense precipitation over a large portion of a river basin area, intense snowmelt combined with precipitation, or intense run-off caused by rain-on-snow, particularly across frozen ground. Riverine flood severity and timing are strongly influenced by storm characteristics (e.g., area, orientation, and intensity) and river basin characteristics (e.g., drainage area, orientation, topography, land cover, initial or antecedent conditions such as soil saturation levels or presence of a snowpack, channel length, channel geometry, and presence of dams and other water control structures). Riverine floods could contribute to a flood of interest at any site adjacent to the river.

The meteorological conditions that cause riverine flooding are essentially the same that occur during LIP flooding (i.e., large storms with heavy precipitation and wind, sometimes thunder, lightning, or hail), but over a much larger area. Therefore, those environmental conditions could occur at a site with a riverine flood, as could the other storm conditions described in Section 2.3 such as low cloud cover, humidity, noise, and standing or moving water. However, depending on the size of the drainage basin and the NPP location in the basin, the maximum riverine flood could lag behind the storm so that the most adverse meteorological conditions do not occur at the same time as the severest flooding, or the path of the storm might not cross the NPP site at all. In those cases, environmental conditions might be more limited: moving or standing water, waterborne debris, or noise and vibration (especially if the site is near a control structure such as a dam). If snowpack were present in the watershed, floodwater could be colder than if there was no snowmelt contribution.

Typically, floods are characterized with respect to the elevation and timing of the flood wave at the site. For the purposes of designing and implementing flood protection and mitigation procedures for NPPs, the complete time history of the onsite floodwater surface elevation (also called the water surface elevation hydrograph, which could result in spatially varying inundation depths on the site) is useful. Weather prediction, storm tracking, and real time river stage monitoring are readily available for major rivers from the NWS forecast maps and NWS Advanced Hydrologic Prediction Center (NOAA-NWS, 2015a, 2015b). Thus, riverine floods may have longer, and possibly more reliable, warning times than floods caused by other FCMs. However, flood warnings may not be available for smaller, local streams; these streams may be subject to flash floods for which the warning time would be short.

2.2.3 Dam Failures

Failure of upstream dams and other water control structures can result from hydrologic failure related to flooding in streams and rivers (see Section 2.2.2), from a seismic event, and some form of structural weakening of the dam or embankment. Non-seismic and other non-hydrologic dam failures are referred to as sunny-day dam failures. Release of stored water following a failure could contribute to a flood of interest at any site. The elevation and velocity of the floodwater would be influenced by the distance of the failed structure from the site, and the amount of additional water released from behind the structure relative to the streamflow if the structure had not failed. The environmental conditions directly associated with a dam failure flooding event would be moving water and waterborne debris, standing water, debris and sediment deposition, and possibly noise. Meteorological conditions during a dam failure flooding event could be anywhere in the range of expected conditions that could occur at the site. In the case of a hydrologic dam failure, these could be the same as the event causing the riverine flood (i.e., heavy rain, wind, cloud cover, and humidity). For non-hydrologic dam failures, the environmental conditions could be more limited: standing or moving water, waterborne debris, debris and sediment deposition, and possibly noise. Floodwater temperature would be influenced by the temperature of the water stored behind the dam relative to ambient temperature. However, as with riverine flooding, meteorological conditions may not coincide with the flooding event at the NPP site.

As with riverine floods, the flood hydrograph adjacent to the NPP site and onsite spatially variable inundation depths caused by the dam failure flood is of interest. Warning times for dam failure floods would depend on the failure mechanism, distance of the NPP site from the dam, and flow characteristics of the flood in the river or stream channel.

2.2.4 Coastal Surge and Seiches

Storm surge or seiches cause or contribute to the design-basis flood at over 25 percent of U.S. NPP sites, and could contribute to a flood of interest at any site near a large waterbody. Most storm surge is associated with hurricanes or strong tropical cyclones (see Section 2.4.1); however, storm surge in the Great Lakes is associated with large frontal systems and in the north Atlantic with nor'easter storms. As described in Section 2.2, storm surge is the rise in offshore water elevation caused principally by the shear force of strong winds acting on the water surface, with a secondary rise in water surface caused by the lowering of the air pressure within a hurricane (NUREG/CR-7046; Prasad et al., 2011). When the storm surge reaches land, surge wave height and force are influenced by many factors: storm size, speed, and intensity; coastline shape, topography, and whether there are barrier islands; offshore shelf slope; and angle of approach to shore. A wide, shallow shelf slope will produce a higher surge than a steeper shelf slope, but a steeper slope will produce bigger, stronger waves given the same storm intensity. Flooding results when the total water level (storm surge plus tides and waves) exceeds the coastal ground level (NOAA, 2015a, 2015b).

A storm surge flood would be characterized by moving water and waterborne debris accompanied by strong winds and likely heavy rain and noise. Water velocity can be very fast depending on the wind speed and the force of waves or tides in addition to the surge height. A large storm could also cause riverine flooding due to co-occurring precipitation over the watershed, which could further increase the elevation of coastal floodwaters and increase the severity of flood-related environmental conditions. Other environmental conditions could be cloud cover resulting in poor visibility, high humidity, standing water, sediment or debris deposition, windborne debris, and vibration. Standing water and deposited sediment or debris could persist long after the surge event occurs.

Seiches occur in semi-enclosed or enclosed bodies of water when some external force, typically meteorological, causes oscillation of the water surface resulting in a standing wave. Seiche wave heights are greatest at the ends (shores) when the wave oscillates about a single center point or node in a waterbody. Storm surge can turn into seiches when a sudden drop in wind speed or atmospheric pressure allows the water pushed up by the wind to slosh back toward the opposite shore. Wind driven waves can also be deflected at an angle from one shore toward another (ISGS, 2015; Wüest & Farmer, 2002). Environmental conditions that could occur with a seiche flooding event would be similar to storm surge: moving water, standing water, waterborne debris, and sediment or debris deposition. The abrupt changes in atmospheric pressure that could generate a seiche are usually associated with a storm front where high winds, rain, and thunderstorms could occur. However, storm conditions are not always present where and when the seiche affects the coast.

Warning times for storm surge can be of the order of several days (NOAA, 2015b). Meteorologically induced seiches may also have relatively long warning times because the frontal system would likely develop over several days. Seismically induced seiches may have shorter warning times because of difficulties associated with predicting or forecasting seismic events.

2.2.5 Tsunamis

Tsunamis are ocean waves typically generated by seismic activity, submarine or subaqueous landslides, and volcanism (NUREG/CR-6966: Prasad, 2009). Tsunami-like waves caused by landslides can occur in inland lakes and rivers; therefore, tsunamis and tsunami-like waves could contribute to a flood of interest at any site affected by these phenomena. If the disturbance is close to a coast, the tsunami can reach the coast in minutes. Environmental conditions directly related to a tsunami flooding event would be moving water, waterborne debris, and likely noise and vibration. Other conditions could be standing water, humidity, and deposited sediment or debris that could persist after the event. Water temperatures would be above freezing but could still be very cold. Tsunamis were considered in several deterministic combinations of flood causing mechanisms (e.g., combined with the 10 percent exceedance high tide and 2-year winds for the site, which would add wind to the relevant environmental conditions and could increase the severity of wave-related conditions). Because seismically generated tsunamis are not weather related, a coastal NPP site could experience any of a range of meteorological conditions at the time of a tsunami. However, landslides can be triggered by heavy rains that saturate soils and may result in some likelihood of concurrent weather conditions for near-field landslide generated tsunami-like waves.

Warning times for seismically generated far-field tsunamis can be from several hours to several days (NOAA, 2015c). Near-field tsunamis often arrive in a matter of minutes.

2.2.6 Ice Effects

Ice jam formation requires subfreezing water temperatures accompanied by turbulence for a freeze-up jam, usually in early or mid-winter, or a sharp increase in temperature or rainfall in an ice-covered river causing a mechanical breakup jam in early spring. The environmental conditions related to an ice jam flood of interest are likely to be cold air temperatures, moving or standing cold water, and in some cases snow on the ground, waterborne debris, and sediment or debris deposition. If a freeze-up ice jam occurs and causes flooding of an NPP site, subfreezing air temperatures and ice are likely to be present at the site. The breakup of an upstream ice jam could occur far upstream of an NPP site and freezing, or ice-related conditions may or may not be present at the site. However, precipitation or snowmelt due to warming temperatures or rain events that precipitated the ice breakup could occur. Therefore, riverine ice effects could contribute to a flood of interest at any site affected by these phenomena.

Ice jams can develop over both significantly long periods and short durations. Subsequent breakups of jams are sometimes foreseeable in a general sense; however, flash flooding often accompanies their sudden breakup. Warning times for the possibility of these events may be a few hours to several days depending on the dynamics of ice accumulation, while impacts of an actual jam may occur with little warning and often occur at night, making lighting an environmental condition of concern.

2.2.7 Channel Diversion or Migration

A flood resulting in diversion or migration of a channel toward an NPP site would likely be the result of more widespread river, stream or seiche flooding that could also cause failure of man-made channels, canals, or levees and could contribute to a flood of interest at any site affected by these phenomena. Therefore, the environmental conditions associated with this FCM would be moving water, waterborne debris and wind, and probably standing water and sediment/debris deposition. The site could experience the same range of meteorological conditions as those experienced during river and stream floods: precipitation (mostly as rain), possibly accompanied by wind, humidity, poor visibility, and noise. Air and water temperatures would be variable, but generally above freezing. A channel diversion of significant severity to affect NPP sites may occur during large floods; warning times may be consistent with the antecedent flooding events.

2.2.8 Combinations of Flood causing Mechanisms

NRC flood hazard assessment guidance (e.g. RG-1.59; NRC 1977) considers floods from individual FCMs in combination with other mechanisms or events that could contribute to floodwater elevations if they occurred prior to, concurrent with, or closely following the main flood event (ANS, 1992; NUREG/CR-7046; Prasad et al., 2011). Examples of expected concurrent events are wind induced wave activity with most riverine and coastal flooding scenarios, snowmelt with cool season rainfall induced riverine flooding scenarios, and high tides with coastal flooding scenarios. Non-concurrent events include antecedent or subsequent precipitation or antecedent snowpack. The suite of environmental conditions relevant to combination of FCMs could include all conditions associated with each component FCM, as summarized in Table 2.1.

The NRC guidance also considers reasonable and plausible combinations of individual FCMs at individual severities less than their respective extreme conditions. Because this report considers floods over a large range of magnitudes, possible combinations of individual FCMs are considered with additional events or with other FCMs, independent of their severity, for the purpose of identifying the ECs that may be present during a flood of interest. Also, FCMs and combinations of FCMs can lead to multiple ECs (e.g. rain and wind) which will be discussed later.

2.3 Identified Environmental Conditions

The suite of environmental conditions that are associated with a flood of interest was used to develop the primary ECs of concern that could be present while flood protection and mitigation procedures are carried out and affect the performance of MAs. Most of the ECs considered by

Table 2.1 Combinations of flood causing mechanisms considered in identification of environmental conditions

Individual Flood Causing Mechanism	Events Considered in Combination						Other Flood Causing Mechanism(s)
	Wind Induced Wave Activity	High Tides	Snowpack, Snowmelt, Rain-on-Snow	Antecedent or Sub-sequent Precipitation	High Water Level in Enclosed Waterbody	Earthquake	
Local Intense Precipitation				X	X		
Streams and Rivers	X	X[(a)]	X	X	X		Dam Failure, Storm Surge, Seiche
Dam/ Structure Failures	X	X[(a)]		X	X	X	Streams and Rivers
Storm Surges	X	X		X	X		Seiche, Streams, Rivers, Tsunami
Seiches	X			X	X	X	Storm Surge, Tsunami
Tsunamis	X	X		X	X	X	Storm Surge, Seiche
Ice Jams	X		X	X	X		
Channel Diversion/ Migration	X			X	X		

(a) High tides are considered in streams and rivers if the NPP is located in the zone of tidal influence.

Sources: ANS, 1992; NUREG/CR-7046 Prasad et al., 2011

Echeverria et al. (1994) (i.e., heat, cold, noise, vibration, and lighting) would also be present in association with a number of flood causing mechanisms. However, several identified ECs that are important in unsheltered work were not addressed in the 1994 review. In particular, precipitation is an EC associated with many FCMs, and is included in this report. However, specific types of precipitation (e.g., rain, sleet, and snow) or degrees of intensity are not listed separately at this point, largely due to lack of research about their effects on performance. In this report, the research team has separated some aspects of ECs that were combined in the earlier work to discuss performance impacts outside those considered by Echeverria et al. (1994). Humidity is such an example. Echeverria et al. (1994) treated humidity in the context of high temperature (heat) as far as the impact on human performance was concerned. However, humidity is associated with a variety of other impacts, ranging from fogging eyewear and displays to tool slipperiness. Another example is wind, whose impacts were also closely tied to temperature. However, under the external conditions considered in this report, wind can have substantial effects on human actions (e.g., walking speed and risk of falling).

In addition to the primary ECs, several secondary ECs could be brought about by one or more of the primary ECs. Slippery surfaces could occur with rain, ice, or snowpack; condensation could occur with the right combination of temperature and humidity; windborne debris (dust, missiles, or snow) or waterborne debris could likewise occur with the right combination of conditions.

The results of the literature review of the ECs are summarized in Chapter 8 and detailed in Volume II. The 11 ECs of concern for flood mitigation and protection actions reviewed in this report are:

1. Heat
2. Cold
3. Noise
4. Vibration
5. Lighting
6. Humidity
7. Wind
8. Precipitation
9. Standing and Moving Water
10. Ice and Snowpack
11. Lightning

3 IDENTIFICATION AND CHARACTERIZATION OF MANUAL ACTIONS

This chapter describes the manual actions (MAs) identified from available sources in which flood protection and mitigation activities were described. The research team characterized the MAs based on their purpose and whether the actions would be performed in sheltered or unsheltered locations.

3.1 Introduction

This chapter describes how MAs were identified that might be performed at U.S. nuclear power plants (NPPs) in response to external flooding events. For the purposes of this report, an MA is defined as a distinct group of tasks performed outside the main control room (MCR) to protect the NPP or mitigate flooding impacts that require human action to accomplish. This definition is similar to that used for operator manual actions in a fire event[1]; however, this report expands this definition to include other types of plant staff. As the term is used in this report, MAs consist of a set of tasks associated with distinct flood response functions (e.g., installing flood panels on door openings, building a berm around a structure using sandbags, or installing and operating a portable sump pump). Consistent with industry's use of the term, the use of MA here is not meant to imply that the action is limited to a physical action performed without the aid of equipment. Rather, MA denotes that the action is taken outside the MCR. The action could involve operating local controls, installing flood barriers, or setting up portable equipment. It is the performance of these actions that would be affected by the environmental conditions (ECs) during a flooding event.

3.2 Identification of Manual Actions

Because an inventory of MAs was not available, a two-pronged approach, as illustrated in Figure 3.1, was employed to identify MAs associated with flood protection and mitigation activities that might be performed at NPPs. It should be noted that the MAs identified by this process are not intended to represent a complete list of the MAs that might be performed at U.S. NPPs. In addition, because the research team did not have the opportunity to review the MAs identified by this two-pronged approach with any NPP personnel or other subject matter experts, the MAs and their characterization should be viewed as a first approximation only.

3.2.1 Wide Cross Section Approach

In the first approach, the research team reviewed and summarized a wide cross section of flooding walkdown reviews across U.S. NPPs to obtain a high-level understanding of the salient MAs that occurred repeatedly in the reviewed documents. The primary source of information was the U.S. Nuclear Regulatory Commission (NRC) staff assessments of the licensees' flooding walkdown reports, which are publicly available.

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[1] NUREG-1852 (USNRC, 2007a, p. xiii) similarly defined manual actions as "those actions performed by operators to manipulate components and equipment from outside the main control room to achieve and maintain post-fire hot shutdown, but not including 'repairs'". Although the focal events are different in NUREG-1852 (i.e., fire) and this report (i.e., external flood), the common defining feature of the manual actions is that these actions take place outside the MCR and are performed by personnel.

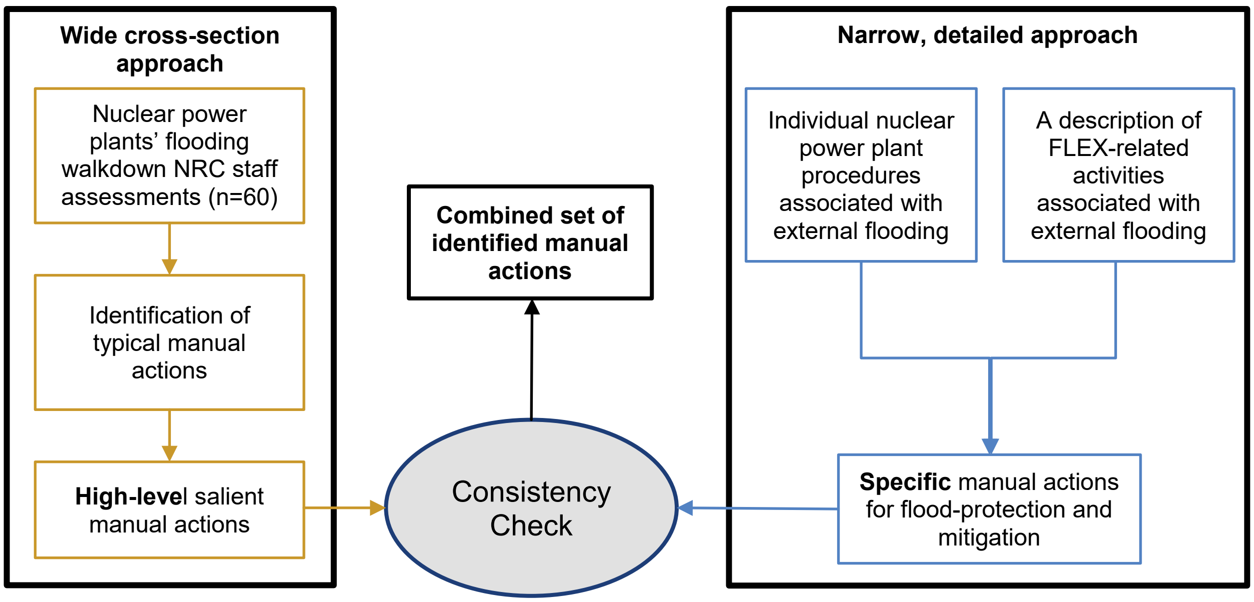

Figure 3.1 Identification of typical manual actions for flood protection and mitigation

As a consequence of lessons learned from events following the 2011 Tohoku earthquake and subsequent tsunami, the NRC requested flooding walkdown reports from power reactor licensees and holders of construction permits. The NRC asked the licensees and construction permit holders to reevaluate the "seismic and flood hazards at their sites using updated seismic and flooding hazard information and present-day regulatory guidance and methodology" (USNRC, 2012b, p. 4). The NRC requested that the licensees and construction permit holders provide further information to support the NRC staff's evaluation of potential regulatory actions to be taken. Specifically, the NRC asked licensees and construction permit holders to conduct flooding walkdowns to identify and address degraded, nonconforming, or unanalyzed conditions and to verify the adequacy of the monitoring and response procedures. The NRC requested the information about the following from the licensees and construction permit holders (see USNRC, 2012d Recommendations 2.1 and 2.3 for flooding).

- design-basis flood hazard level(s) for all flood causing mechanisms
- flood protection and mitigation features considered in the licensing basis evaluation to protect against external ingress of water into structures, systems, and components important to safety
- the effectiveness of flood protection systems and barriers
- implementation of the walkdown process
- findings of the walkdown process, including identification of degraded, nonconforming, or unanalyzed conditions, and corrective actions taken/planned
- cliff edge effects[2] and the associated basis
- planned/newly installed flood protection systems or flood mitigation measures

[2] The US. NRC Near-Term Task Force (NTTF) in response to events at Fukushima Dai-ichi in March 2011, defined the cliff edge effect as a safety consequence of a flooding event that may increase sharply with a small increase in flooding level.

The NRC evaluated the submitted information and summarized it for each NPP in a staff assessment. The research team reviewed, extracted, and compiled the actions, including manual and main control room actions pertaining to flood protection and mitigation, into a matrix (Appendix A). The actions included in the matrix are the most commonly documented in external flooding responses across the staff assessments and are the core example set of MAs in this report.

3.2.2 Narrow Detailed Approach

To supplement and enrich the information obtained from the first approach, the research team also reviewed five detailed NPP flood protection procedures to identify specific MAs required. A description of FLEX activities was also available to the research team. Diverse and flexible coping strategies, or FLEX, is described as an approach to increase defense in depth for beyond-design-basis scenarios to address the extended loss of alternating current power and loss of normal access to the ultimate heat sink occurring simultaneously at all units on a site (NEI, 2016). The second approach, as shown in Figure 3.1, provided information about the instructions to personnel for performing these actions. The limited number of procedures available for review covered required personnel actions in response to a variety of conditions (e.g., dam failure, plant flooding, turbine building flooding, containment flooding, and external flooding) and guidelines for operating under severe weather conditions and natural disasters (e.g., hurricanes, tornadoes, tropical storms, severe thunderstorms, and seismic events).

Some of the procedures were of particular interest because they provided more extensive information about MAs, both in terms of number of actions and level of detail. To illustrate the depth and breadth of MAs identified in some of the reviewed procedures, one site's MAs are presented in Appendix B.

The following list presents a distillation of the MAs identified through this review of procedures:

- Construct a sandbag barrier, berm, or levee around a structure.
- Plug or seal drains.
- Remove or relocate equipment (e.g., fire equipment, security equipment).
- Stage diesel storage tanks or tankers.
- Monitor and clear debris from traveling screen at the intake structure.
- Bolt or weld steel plates over door openings.
- Bolt or weld steel plates over floor drains, penetrations, and hatches.
- Seal structural gaps.
- Relocate, install, and operate diesel pumps.
- Relocate, install, and operate additional electric- or gas-driven sump pumps.
- Route sump pump discharge lines.
- Position or secure hatch cover.
- Monitor water level.
- Monitor intake screens for plugging.
- Fill the lube oil dump tank with water.
- Remove the drive motor and install a hand crank (e.g., traversing the rake).
- Provide diesel fuel and gasoline to power pumps.
- Scarify or rip concrete and asphalt surfaces under levee.
- Seal all conduits.
- Plug manholes.
- Rent/obtain watercraft.

- Remove/block ventilation ducts.
- Cap discharge line and drain line.
- Secure ladders.
- Install electrical jumpers.

3.3 Characterization of Manual Actions

The research team grouped the MAs identified in the wide cross section approach according to their principal purpose and the degree of sheltering the individual performing the MA would likely experience (i.e., whether or not the individual performing the action would be outdoors [unsheltered], partially sheltered, or indoors [sheltered])[3] Organized by the criterion of an action being performed with or without sheltering, salient actions identified from the NRC staff assessments were grouped as follows:

- MAs that may be entirely or partially performed outside a facility:
    - Deploy sandbags and build berms.
    - Place flood barriers.
    - Close doors, gates, hatches, and manhole covers.
    - Secure drains, close valves, and seal openings.
    - Set up and operate portable pump and sumps.
    - Equalize pressure (open doors, weight floor).
    - Seal fuel vents and cover air intakes.
    - Monitor leakage, hazards, weather, and debris.
- MAs performed inside a facility:
    - De-energize and adjust electrical power.
    - Operate installed plant sump or pump systems.
    - Connect piping spool to alternate cooling source.
    - Connect electrical jumper to alternate power source.
    - Monitor leakage, hazards, weather, and debris.

Appendix A tabulates the pertinent content extracted from each NPP's NRC staff assessment for each of these actions.

The research team then compared the MAs identified using both approaches to examine the consistency between the MAs identified from the flooding walkdown staff assessments (Approach 1) and those gleaned from individual NPP procedures (Approach 2). In most cases, the specific plant MAs identified using Approach 2 fit into the core MA set identified in the matrix (Appendix A) produced using Approach 1.

3.4 Caveats, Exceptions, and Observations

The first approach provides a high-level, inclusive list of MAs and the second approach yields more detailed information to ensure the high-level actions are consistent and compatible with the actual operating procedures. The information generated by the second approach corroborates that from the first; thus, the research team concluded that the matrix of MAs in Appendix A is a credible foundation for understanding the type and range of flood protection and mitigation MAs at U.S. NPPs. For example, the clearing of debris from the traveling screens at

[3] Actions performed indoors can also be exposed to ECs associated with flooding events such as low or high temperature, high humidity, and poor or no lighting.

intake structures, which may be applicable at some plants, was not identified in the flooding walkdown staff assessments examined. Another example is the transfer of equipment to higher elevations, an action that appears in the external flooding response procedure for some plants. This action could be associated with property preservation instead of, or in addition to, nuclear safety.

Three observations of note emerged during the information assembly for MAs which are important in consideration of human performance:

1. The execution of MAs is not limited to NPP operators. Unlike the choreographed actions directed by emergency operating procedures in which command and control is well established and the primary actions are performed by licensed operators, the flood protection and mitigation MAs may be performed by licensed operators, licensed NPP equipment operators, NPP craft labor, or by contractors brought in from offsite locations[4]. This suggests that establishing clear and effective communication and coordination among different groups of personnel responsible for implementing flood protection and mitigation actions is an important consideration[5].
2. MAs can take place in various locations that have different degrees of sheltering, such as outdoors (no sheltering), indoors (full sheltering), or in semi-sheltered settings. The degree of sheltering is assumed to affect the ECs to which the individual(s) performing the MA are exposed, and therefore their impacts on performance. For example, if an action is performed indoors, the individual may be protected from certain ECs (e.g., precipitation or strong wind) and his or her performance of the action is less likely to be adversely affected by such conditions than if the action were performed without shelter. This distinction was used in the research team's grouping of MAs in the matrix.
3. Flood protection procedures can be initiated before or after a reactor trip. Warning time may allow some actions to occur before reactor trip, however, they still play an important role in risk assessment during a flood event.

[4] The personnel that conduct flood protection and mitigation MAs are referred to as "personnel" throughout this report

[5] Personnel who execute the MAs are assumed to be sufficiently trained or that training will be treated separately from the environmental conditions. Shaping factor such as training and fatigue are not part of this work and likely will be treated separately in any future application

4 OVERVIEW OF THE IMPACT ASSESSMENT APPROACH

To provide insights on what aspects of performance of manual actions are affected by environmental conditions, while maximizing the utility of the available research, the research team selected a task analysis modeling approach. This classical approach was selected for its applicability to address the problem at hand, in which only basic information is available about the nature of the tasks being assessed and their relationships to nuclear power plant (NPP) status, and the tasks generally involve time-consuming physical activities and relatively straightforward decision-making. The proposed task analysis approach supports the development of information that could be used in an assessment process to identify the manual action-environmental (MA-EC) combinations that warrant more detailed analysis. Previous chapters of this report describe the nature of the environmental conditions whose effects are to be assessed and the types of flood protection and mitigation Manual Actions (MAs) that NPP personnel would implement in response. This chapter presents an overview of existing impact assessment approaches that informed the research team in the development of their proposed task analytic approach, which was used as a basis for developing human performance information relevant to the environmental conditions likely to be experienced during flood protection and mitigation procedures.

4.1 Existing Impact Assessment Methods for Environmental Conditions on Human Performance

The assessment of environmental impacts on the performance of MAs can be accomplished using different approaches. In many performance assessment approaches, impacts from weather-related ECs, such as those that are the focus of this report, are not considered, either because the activities being evaluated are taking place in sheltered conditions or the ECs themselves do not vary significantly and/or can be controlled. When the type and potential severity of ECs considered in this report are incorporated into an impact assessment, the full set of environmental conditions is seldom addressed. Instead, the assessment includes only the pertinent subset of environmental conditions considered to have the potential to alter individual or team performance, and most commonly, only those expected to show considerable variability in indoor settings. These include lighting, heat, vibration, and noise. In addition, the principal assessment methods developed for application at NPPs address the performance of tasks in which the physical effort (and the time spent performing the physical action) is inconsequential. These methods therefore focus on estimating probabilities of errors rather than penalties on performance time. However, some of the methods developed to assess the impacts of ECs on the performance of tasks that involve extensive physical activity, such as those performed by soldiers, place primacy on estimating the impacts on performance time.

The following sections briefly review existing methods to assess human reliability, focusing on the impacts of environmental conditions. Methods reviewed are from a variety of industries including Nuclear Power, railroad and military.

4.1.1 Probabilistic Risk Assessment and Human Reliability Analysis for the Nuclear Power Domain

Analysts conducting performance impact assessments for NPPs have developed methods to address pertinent environmental conditions as part of probabilistic risk assessments (PRAs). In some PRAs used for NPPs, the assessment focuses on how the environmental conditions would affect the performance of human failure events (HFEs) which are defined as basic events that represents a failure or unavailability of a component system or function that is caused by human inaction or inappropriate action[1]. These assessments typically draw upon extensive prior analysis that has identified and characterized the HFEs and is supported by further analysis to establish human reliability in performing these actions under normal or baseline conditions. In human reliability analysis (HRA) methods[2] used to support PRAs, modifications of baseline conditions that are likely to affect performance in a way that increases or decreases the human error probabilities (HEPs) of HFEs are termed performance shaping factors (PSFs).

In HRA, the concept of PSFs, also labeled performance influencing factors (PIFs), is central to estimating HEPs. A PSF or PIF is defined as “a factor that influences human performance and human error probabilities, including time available, stress/stressors, complexity, experience/training, procedures, ergonomics/human-machine interface, fitness for duty, and work processes” (NUREG/CR-6883, Gertman et al., 2005).When the environmental conditions, that are the focus of this report are addressed in HRAs, they are typically addressed as PSFs and contribute to the development of HEPs[3]. Consequently, in these HRAs, the effects of a particular EC (e.g., high air temperature, loud noise) are usually being assessed for highly specified activities and the impact is assessed in terms of its effect on the probability of error in performance of the HFE, i.e., impact on the HEP.

As noted in NUREG-1792, Good Practices for Implementing Human Reliability Analyses, PSFs are characterized as having a weak/strong positive, neutral (or not applicable), or negative influence on the probability of human error, regardless of the specific method or tool being used, to translate information about a PSF into a quantified HEP (NUREG-1792, USNRC, 2005). Values of PSFs are based on empirical data, if available, and/or expert judgment. In one approach, shown in Table 4.1, nominal (baseline) HEPs are multiplied by the influence value of the PSFs to derive HEPs that reflect the impact of the PSF (SPAR-H, Blackman et al., 2008; Boring & Blackman, 2007). The influence value of the PSF represents its entire spectrum of performance impacts on the HEP for that HFE. For each HFE, these values often reflect prior research on the types of errors that might occur, how the various PSFs affect the probability of those errors, and the consequence of those errors on the probability of an HFE.

Environmental conditions, referred to as environmental stressors in HRA, are typically considered along with other PSFs to quantify HEPs. HRA methods reviewed in this work include the Technique for Human Error-Rate Prediction (THERP, NUREG/CR-1278, Swain &

Table 4.1 Relationship between PSF and HEP

$HEP_{overall} = HEP_{nominal} * PSF$	0<PSF<1	$HEP_{overall} < HEP_{nominal}$	Enhancing reliability
	PSF = 1	$HEP_{overall} = HEP_{nominal}$	No impact on reliability
	PSF > 1	$HEP_{overall} > HEP_{nominal}$	Reducing in reliability

Adapted from Boring, 2010, Equation 1

[1] Lighting, heat, vibration, and noise and other environmental conditions considered pertinent, for example, smoke and radiation

[2] In HRA, the definition and analysis of HFEs, along with the quantification of the failure probability of HFEs, relies on a range of analytic methods that typically involve a sound task analysis to derive an understanding of the factors most relevant to the action (NUREG-1792, USNRC, 2005).

[3] In an HRA of NPP personnel actions, performed in the main control room or other indoor locations, other factors such as task complexity, available time, and workload are typically dominant concerns.

(NUREG/CR-6883, Gertman et al., 2005), and the Integrated Decision-tree Human Error Analysis System (IDHEAS, NUREG-2199 Volume 1: USNRC, 2016a). In THERP, environmental stressors include temperature, humidity, air quality, noise, vibration, illumination, and degree of general workplace cleanliness (Boring et al., 2007). In SPAR-H, environmental conditions are part of a PSF called stress/stressors, which includes conditions such as heat, noise, ventilation, and radiation (Blackman et al., 2008). In SPAR-H, the impacts of stressors are operationalized by using multipliers that increase HEPs for levels of the stressor (e.g., the multipliers for extreme stress = 5, high stress = 2, and nominal stress = 1, as noted by Blackman et al. (2008).

These HRA methods have been primarily applied to actions performed indoors, where the physical environment is controlled, except during unusual circumstances such as a fire event. NUREG-1792 (USNRC, 2005) notes that actions taken outside the main control room could be subject to ECs (e.g., those from radiation, lighting, temperature, humidity, noise, smoke, toxic gas, weather) sufficient to impair performance, perhaps even preventing individuals from performing some actions. A scoping quantification approach introduced in USNRC, NUREG-1921 (USNRC, 2012a) adjusts HEPs with respect to different levels of smoke, heat, and toxic gases and provides guidance on how to adjust THERP HEPs to represent the influence of other environmental conditions (e.g., low or emergency lighting).

4.1.2 Danish Railway Task Analytic Approach with "Generic Tasks"

The Technical University of Denmark developed a task analytic approach to support the introduction of a new signaling system for the Danish railways. Their approach uses PSFs with multipliers in combination with what they called "generic tasks" to support a task level quantitative HRA (Thommesen & Andersen, 2012). The approach uses estimated HEPs based on and extrapolated from literature. Thommesen and Andersen developed a list of generic tasks for the analysis that were designed to be applicable to the rail domain and representative of tasks that would be performed upon adoption of the new signaling program. They justified the use of a first-generation HRA method (Human Error Assessment and Reduction Technique [HEART]) because it focuses on the skill-based and rule-based levels of human action and is less resource intensive to use than other alternatives. This method is recognized as relatively ineffective in addressing errors of commission and is not well suited to predicting and capturing actions performed by individuals outside the scope of predefined or predicted task scenarios. However, it is considered informative and cost effective for a new and yet to be deployed application, such as a new signaling program. Thommesen and Andersen argue that it is appropriate to begin by applying a first-generation method, while reserving the more complex methods that may capture lack of resilience against less common and ill-defined situations until task relationships and skills and knowledge requirements have been defined. The set of seven generic tasks Thommesen and Andersen developed for this assessment are shown in Table 4.2 which illustrates the use of highly abstracted generic actions in an impact assessment.

4.1.3 Task Analysis for Activities that Involve Extensive Physical Effort

Impact assessment methods developed by other organizations, such as the U.S. Army Research Laboratory (ARL), focus more on consequences in terms of time, effort, and errors than on human reliability and risk metrics. The ARL approach was developed to inform analyses of human versus system function allocations, mission effectiveness, maintenance staffing determinations, mental workloads, predictions of human performance under extreme conditions (including weather conditions), and performance as a function of varying personnel skills and abilities (Allender, 2000). Some of the research conducted by the ARL has focused on

Table 4.2 Generic tasks as described by Thommesen and Andersen

Task	Description
Human performance limit	The highest obtainable reliability (minimal error rates; based on Kirwan, 1994)
Simple routine	Simple, familiar, and frequent task; skill-based or rule based performance and judgment (e.g., normal tasks involving a deviation from planned operations; based on HEART Hickling, 2007)
Nontrivial familiar	Familiar, relatively frequent task, requiring knowledge-based performance and judgment; normal tasks involving a deviation from planned operations
Communication, routine	Familiar content routinely conveyed, and where at least a limited template for communication is available, and error capture and correction are possible
Communication, nonroutine	Unforeseen, novel content, where no template—or only a rudimentary one—is available.
Emergency scenarios, known	Task characterized by some urgency and stress due to safety or production concerns, for which a plan of action (a template, a script) and relevant information are available
Emergency scenarios, unknown	Task characterized by a high degree of urgency and stress due to safety or production concerns where no adequate plan of action (a template, a script) is available, and relevant information is uncertain or missing

Source: Thommesen and Andersen (2012)

understanding how outdoor ECs affect the performance of soldiers in their interactions with systems and operating environments (e.g., Salvi, 2001). In ARL's approach, the effect of environmental stressors on the time and accuracy of task performance is the focus of the assessment. A task analytic approach similar to ARL is particularly appropriate for the assessments discussed in this report, in which the sequencing of tasks is not yet clearly delineated and may be flexible and the relative contribution of the tasks to higher level performance measures (e.g., plant status) is not clearly specified.

In ARL's approach, currently represented by the stochastic network modeling tool IMPRINT (Improved Performance Research Integration Tool: ARL, 2017), missions are decomposed into functions (i.e., a process or activity required to achieve a desired goal; NUREG-0711, Rev. 3: USNRC, 2012c), which are then further decomposed into tasks and subtasks. The IMPRINT software is designed to explicitly model the relationship among tasks, including repeating, branching, and recovery tasks and provides an appropriate computation framework of network relationships. Tasks (or subtasks, as needed) are defined at a level of detail that permits characterizing them in terms of ability and performance requirements (defined as taxons; Allender, 2000; Salvi, 2001). Ideally, the analyst has, or can develop or estimate, the following information about each of the tasks:

- time and accuracy – the length of time the task usually takes to complete and the likelihood of failure under baseline conditions;
- effects – the circumstances that must occur before, during, and after the task;
- failure – the consequences of task performance failure;
- crew – the personnel who will be performing the task;

- taxons – the categorization used to describe the workload composition of the task;
- paths – the decision logic describing the conditions under which each of the individual paths leaving a task is taken; and
- workload demand – value(s) indicating the relative demand on the individual performing a task.

The ARL's assessment approach analytically differentiates the varying impacts of stressors on different aspects of human performance associated with tasks. The approach uses performance degrading (or enhancing) factors and degradation (or enhancement) algorithms based on research and expert judgment that quantitatively relate a stressor to its effect on a task's taxons (O'Brien et al., 1992; Salvi, 2001; Wojciechowski, 2007). By contrast to the NPP HRA methods discussed above where the PSF increases or decreases, the HEP, and therefore the probability of an HFE, the ARL's task analysis approach estimates the effects of the stressor on aspects of human performance associated with the task, (i.e., the taxons), and from that, estimates the effect on performance. The method is also designed to reflect whether the research indicates that the stressor primarily affects the time or accuracy of taxons (Bagnall & Sargent, 2008). In the assessment of tasks involving outdoor activities similar to those identified as MAs and stressors similar to the ECs, the ARL approach allows a focus on impacts on time, which may be important in assessing success of an MA.

The ARL approach builds upon the function and task analysis. A branching logic tree determines how the functions and tasks are connected at their respective levels, indicating whether functions and tasks are repeated, performed simultaneously, serially, or probabilistically. It is at the basic task level, the lowest level, where detailed information such as accuracy and time data reside.

To access the Stressor capability in IMPRINT, a task is defined by "taxons." which depict inherent task characteristics and a weighting scheme is used to describe the degree to which a particular task relies on a particular taxon. For example, the task of repositioning a helicopter in flight may involve maneuvering the aircraft, which is classified as fine motor-continuous, and sending or receiving information by radio, which is classified as communication (oral). The analyst chooses the applicable taxons and IMPRINT applies the environmental stressors, referred to as performance degrading factors, in the IMPRINT lexicon, proportionally with respect to the taxons associated with each task. The ARL approach uses a taxonomy that has nine categories (O'Brien et al., 1992; Wojciechowski, 2007). These taxons are (1) visual cognition/visual discrimination, (2) numerical analysis, (3) information processing/problem-solving, (4) fine motor-discrete, (5) fine motor-continuous, (6) gross motor light, (7) gross motor-heavy, (8) oral communication and (9) written communication. If a task involves multiple taxons, the impact of a stressor on task performance is estimated by: (a) calculating the effect on time or accuracy due to the effect of the stressor on each taxon, weighted by the percentage the taxon constitutes of the task, and (b) summing the effects from the constituent taxons (Salvi, 2001).

IMPRINT analysts rely upon prior research and expert judgment to specify the percentage of each taxon associated with a task. Performance degradation/enhancement factor values are based on basic research, empirical studies, previous experience, expert opinion gathered through surveys or questionnaires[4], or informed estimates (O'Brien et al., 1992; Salvi, 2001; Schipani et al., 1998; Wojciechowski, 2007).

[4] Studies using IMPRINT have mostly been focused on evaluating military activities and personnel performance degradation.

4.2 Proposed Framework to Apply Results from the Research Literature to Assess Impacts on Manual Actions

Based on the nature of the flood protection and mitigation tasks being evaluated and the limited information available about the MAs and their relationships to plant status, the research team concluded that a task analysis framework and approach, adapted from ARL, offered a suitable method for assessing the impacts of the environmental conditions being addressed in this report. Consequently, as described in Chapters 5 through 8, the research team applied this framework and approach in (1) reviewing the research literature to establish performance measures, worker ability, and task demand characteristics; (2) decomposing MAs into tasks, subtasks, and specific actions and characterizing them in terms of the demands they impose on those performing them and (3) summarizing what research was found about how the ECs that may prevail during flooding events affect performance demands and task performance. The team also discussed an extended framework to generalize specific actions when conducting an analysis across a large set of plants or for identifying what ECs might prevail during flooding events.

It should be noted that information about HEPs and the impact of environmental PSFs developed by research supporting the various HRA methods can be combined with information developed to support the proposed task analytic approach described in this report. However, it is also important to recognize the preliminary nature of the impact assessment process for the MAs identified in Chapter 3. Information was not available about the performance of these MAs under normal conditions, the time available, their interrelationships, or the consequences of failure to complete them successfully. Consequently, the proposed framework is designed to illustrate steps that could be taken to collect and/or generate some of the information needed to conduct a detailed impact assessment within the proposed approach. This process would identify the MA-EC combinations that warrant more focused attention and clarify the aspects of task performance most affected by the ECs. The proposed approach can be refined in the future as site-specific assessments are performed and lessons learned are incorporated.

5 HUMAN PERFORMANCE MEASURES, ABILITIES, AND TASK PERFORMANCE DEMANDS

As part of the review of the research literature and development of the impact assessment approach, the research team examined the measures used to account for the impact of environmental conditions (ECs) on human performance. They also reviewed how researchers and impact assessors describe and categorize human abilities and task demands when their purpose is to apply research findings to the explanation or assessment of impact on the performance of different types of tasks. They paid particular attention to how impact assessment methods used or developed by the U.S. Nuclear Regulatory Commission (NRC) to address these issues would apply to the problem at hand, in which the human actions occur outside the main control room; often involve extensive and demanding physical action; are not highly proceduralized and may evolve as the flood event continues; and often require movement from one physical location to another.

Based on consideration of the purposes of this project, the type of human actions being addressed, the nature of the environmental conditions, and the variables addressed in the human performance research literature, the research team concluded this chapter by introducing a taxonomy which it calls performance demands.

5.1 Measures of Human Performance

To assess the impact of ECs on the performance of manual actions (MAs) associated with flood protection and mitigation, it is important to clarify the dimensions of performance that are pertinent to the purpose of the assessment. The human factors research literature identifies many different measures for assessing how well a task is performed. Wreathall (2000) set forth the following desirable characteristics of human performance measures:

- Objective: not easily manipulated or not involving judgments that can be arbitrary.
- Quantitative: to allow trending and comparison with other measures.
- Simple to understand/represent worthy goals/possess face validity: to reinforce and encourage improved performance.
- Related to/compatible with other programs: if possible, measures should be integrated into existing programs to affect efficiency as minimally as possible.

Gawron (2008) categorized performance measures into six groups, reflecting the various ways human factors researchers have addressed task performance. Wickens et al. (2016) have delineated accuracy, speed, and attentional demand[1] as "the big three" in performance assessment. The "big three" are reflected in personnel safety and personnel error concerns pertinent to the nuclear power domain (e.g., error or incident rates). Of these, the two that are the focus of the assessment of the impact of ECs on the performance of specified tasks, within this work, are (1) accuracy and (2) time[2]. "Accuracy" measures the degree of correctness in

[1] Workload and attentional demand (i.e., the amount of visual and cognitive attention required to complete a task (Mazloumi et al., 2010) have been identified as important task characteristics that affect human performance.

[2] The remaining measures are (3) task batteries, (4) domain-specific measures, (5) critical incident measures, and (6) team performance measures. "Task batteries" are made up of multiple tasks designed to measure a range of basic abilities representative of different domains. "Domain-specific measures," in contrast, are focused on components of a family of related tasks. "Critical incident measures" are typically used to identify factors associated with worst case performance, for example physiological measures of environmental tolerance that set boundaries for safety (e.g., heat and/or cold). "Team performance measures" assess the abilities of teams (e.g., two or more persons) working

performing a task given that there is a known and correct way to perform a task. “Time” measures the speed of performing a task given that there are well-defined beginning and ending points for the task.

In practice and experimental studies, tradeoffs between aspects of performance, especially between accuracy and performance time, are frequently observed and investigated (Heitz, 2014; Salvi, 2001; Wickens et al., 2016; Wood & Jennings, 1976). At the same time, it has been noted that some of the cognitive phenomena that occur during task performance and affect performance time and/or accuracy are not directly observable (e.g., learning, memory, quality of mental models[3], situation awareness, and overconfidence in decision-making). ECs can affect these cognitive processes and affect performance time and/or accuracy.

Based on a review of the salient human performance literature, the research team concluded that one of the most important impacts of ECs associated with external flooding events is an increase in the time needed to perform required MAs (other performance measures, especially accuracy, can also be useful for assessing the performance of MAs). EC impacts on performance time are widely addressed in the research literature (e.g. Gawron, 2008; Wickens et al., 2016). The effects of environmental conditions (and the duration of exposure to them) have been shown in experiments to impair time of performance and accuracy, unless extra time is used (e.g. for cold, Allan et al., 1974; for vibration Schipani et al., 1998). Perkins et al. (2011) note that for large external flood events (particularly dam failure), depending on active flood mitigation procedures is a “major factor in uncertainty” in risk is the response time for the action to be completed after initiation. Schneider et al. (2016) discusses the multiple time dependencies of human performance for flood mitigation actions including interference from non-safety actions conducted by others in preparing the plant for a flooding event, time delays due to sequencing and on recovery from time delays. These are all delays that may require a “need to expedite other actions that may now need to be carried out in a more adverse environment” (Schneider et al., 2016). Dependence on time in operating plants was identified by NRC through the SDP process for 3 NPPs between 2012 and 2013 (USNRC, 2013a, 2013b, 2013c). These SDPs were results of a plant’s inability to maintain or implement flood mitigation procedures considering all actions within the credited time.

Both operational research literature and operational experience show that, beyond time for completion, lack of accuracy (e.g., a step of a task performed erroneously or skipped entirely) can have significant impact on performance (Hallbert et al., 2006). However, the relatively protracted time over which many flood protection and flood mitigation actions take place (e.g., building berms and placing barriers) often provides ample opportunity for workers to detect and recover from errors. The ability to recover from such performance errors can allow the assessment of accuracy to be evaluated as an increase in time for the manual action to be completed (Schneider et al., 2016). Consequently, these human errors that lead to inaccurate performance in external flood mitigation tasks (which are allotted sufficient time for recovery and additional attempts) may be assessed in terms of the time it takes to recover from those mistakes and their effect on total task times. It should be noted that influencing factors beyond accuracy and available time (or time delays) are likely to be important to the success of a task.

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together to accomplish a common task. All six groups of these measures were found in literature that explored the environmental effects on performance, but the primary focus of the examples and proof-of concept model has been on speed performance time and accuracy.

[3] A mental model is a person's internal, personalized, contextual understanding of how something works, (i.e., a psychological representation of external reality) that is hypothesized to play a major role in cognition, reasoning, and decision-making.

5.2 Human Performance, Task Demands, and Macrocognitive Functions

The goal of the assessment and the nature of the impacting agents affect the information about human performance and task demands that analysts need to support the assessment of impact. Unlike many factors whose impact on performance has been the subject of inquiry and assessment, the ECs addressed in this report have the potential to affect both human abilities (e.g., by affecting the individual's sensory systems, physical strength) and task demands (e.g., increasing the physical effort required to remain upright; increasing the navigation requirements to reach a target destination). Consequently, the research team concluded that the dimensions used to describe the tasks to be performed should also be appropriate for describing the human abilities required to perform the tasks and, to the extent possible, the way the research literature describes the mechanisms and effects of the environmental conditions being assessed. Research on human performance and task analysis highlights the importance of linking task demands with performance theory to facilitate the interpretation or prediction of environmental impacts on task performance.

Studies of human performance point out that performance theory enables the basic research on dimensions of performance assessment to be brought to bear on clarifying the performance implications of particular stressors. As Sanders (1998, p. 471) asserted, "It [performance theory] is the only way in which decomposed elements of real-life tasks can be related to corresponding performances, as studied in the basic literature." A significant purpose of this project is to identify and review relevant basic research literature regarding the impact of the environmental conditions identified in Chapter 2 on the performance of the type of MAs identified in Chapter 3. The research team reviewed the taxonomies developed in performance theory and those reflected in NRC human reliability analysis (HRA) and human factors research and methods to inform not only the description of the MAs but also the research literature review. Taxonomy is defined here as a classification system to simplify complex events and objects so that useful relations among them, such as similarities and distinctions as well as patterns, are established (Miller, 1967).

Researchers have developed a host of taxonomies of human performance since the 1960s (Lance et al., 2013). Fleishman (1975) distinguished four approaches to classifying worker performance:

- the behavior description approach (Fine, 1963; McCormick, 1964)
- the behavior-requirements approach (e.g. Annett & Duncan, 1967)
- the ability-requirements approach (Fleishman, 1975)
- the task characteristics approach (Farina & Wheaton, 1971; Hackman, 1970)

The actual taxonomies used in impact assessment methods often reflect combinations of these approaches.

5.2.1 Taxonomies to Support Human Reliability Analysis for Nuclear Power Plants

The taxonomies developed by and for the NRC for the assessment of human reliability in nuclear power plants (NPPs) are focused on understanding and predicting human errors within the highly complex and proceduralized operating environment of an NPP. These taxonomies are designed to identify and estimate the probability of errors and failures. They are designed to be applied to human actions that involve complex decisions that may have to be made quickly, by domain experts, in risky or high stakes situations but that do not involve extended physical exertion or movement. Consequently, this research and these methods have focused on cognitive and psychological processes and sources of errors. For example, in NUREG/CR 5680 Volume 2, human performance and the effects of varying environmental conditions were examined from the perspective of performance abilities, defined as “the human capabilities, such as perception or psychomotor skills, that are necessary to perform tasks” (Echeverria et al., 1994, pp. 2–2). A key conclusion from this research was that a wide range of performance abilities are needed to perform the various tasks at NPPs. Echeverria et al. (2016, p. 2-2 - 2-3) identified a number of key performance abilities and their related measures. According to germane research literature presented by Echeverria et al. (2016, p. 2-2 - 2-3), the performance abilities shown in Table 5.1 are applicable to NPP operator performance and are influenced by various ECs.

Taking advantage of recent developments in cognitive and behavioral science, the NRC reviewed research literature to provide a cognitive basis for human reliability analysis in NPP control rooms (NUREG-2114, USNRC, 2016b). Designed to support the development of the NRC’s HRA method “The Integrated Human Event Analysis System (IDHEAS)”, NUREG-2114 adapted five macrocognitive[4] functions to represent a complete span of NPP operators’ cognition when performing complex tasks (USNRC, 2016b). NUREG-2114 also developed a framework to document the process of the macrocognitive functions, the mechanisms underlying the processes, and the effects of performance shaping factors (USNRC, 2016b). Their broad review of research literature pertaining to cognitive psychology, behavioral psychology, neuropsychology, human factors, and human performance on NPP operator actions also included Chang and Mosleh (2007e, 2007d, 2007b, 2007a, 2007c), O’Hara et al. (NUREG/CR-6947, 2008), and Roth (2010). These macrocognitive functions are listed in Table 5.2.

5.2.2 Taxonomies for Assessments Outside the Nuclear Power Domain

O’Brien et al. (1992) describe another task performance taxonomy. In this taxonomy, task success is a function of personnel characteristics. In general, these personnel characteristics are cognition, perception, psychomotor skill, and physical characteristics. However, building on their own research with U.S. Army personnel and expanding on the work of earlier researchers such as Fleishman and Quaintance (1984), O’Brien et al. (1992) ultimately identified a broader set of characteristics and generated a task taxonomy to predict worker performance, given

Table 5.1 Performance abilities and measures from NUREG/CR-5680

Performance Abilities	Measures
Attention	Memory, vigilance, switching
Vision	Acuity, threshold perception, memory
Perception	Pattern recognition, visual recognition
Psychomotor skill	Simple and choice reaction time, coordination, tracking
Manual dexterity	One hold test, flexibility
Cognitive functions	Reading, arithmetic, reasoning
Mood and comfort	Annoyance, sense of well-being

Source: NUREG/CR-5680, Echeverria et al., 1994, p. 2-2 - 2-3

[4] Macrocognition describes cognition in real world settings, focusing on the nature of human performance “in the field” and on “what humans do with their brains in applied complex settings.” The five cognitive functions in this approach “interact with each other in a continuous, nonlinear loop involving parallel and cyclical processing” (NUREG-2114: USNRC, 2016b, p. 9).

Table 5.2 Macrocognitive functions and their definitions

Macrocognitive Functions	Definition
Detecting and Noticing	Sensation, perception, attention processes that allow humans to perceive important information in the work environment and focus selectively on those that are pertinent to present activities.
Understanding and Sensemaking	Understanding the meaning of the information detected, evaluating, hypothesizing, diagnosing, and integrating facts and theory. Includes situation awareness and is based on the data/frame theory of sensemaking.
Decision-making	Goal setting, planning, re-planning and adapting, evaluating options, and selection.
Action	Implementing a single manual action or a predetermined sequence of manual actions that involve manipulation of hardware and/or software that affects plant status. A neurophysiological process that is based on hierarchy pathways, automaticity, and sensory feedback.
Teamwork	Team interactions to coordinate work on a task, including coordination, collaboration, and communication between individuals. It specifically includes leadership and supervision as well as crew interaction issues such as command and control.

Source: *NUREG-2114 (USNRC, 2016b)*

varied types of tasks and conditions that could degrade human performance. The characteristics identified in O'Brien's' task taxonomy, which he refers to as "taxons," are listed in Table 5.3.

As previously discussed in Chapter 4, these taxons were subsequently used in a software program, IMPRINT (Improved Performance Research Integration Tool), developed by the U.S. Army to assist in analyses of human performance for a wide variety of tasks. The IMPRINT Pro Users Guide refers to these taxons as elements of "workload composition."

5.2.3 Comparison of Taxonomies

There are, however, differences in the taxonomies. The abilities framework in NUREG/CR-5680 (Echeverria et al., 1994) implies attention to individual differences and explicitly lists mood and comfort, both of which were explicitly excluded from the scope of this project. Given its focus on cognition, the macrocognitive functions framework of NUREG-2114 (USNRC, 2016b) does not include physical motor skills beyond the neurophysiological aspects of action that lead to errors of execution. As noted above, the MAs that are the subject of this report include more extensive physical activities than the human actions that are performed in an NPP main control room and are the focus of the (NUREG-2114, USNRC, 2016b) approach. The taxonomy of IMPRINT does not specifically identify attention but does specifically call out cognitive-numerical analysis. It also collapses other cognitive processes into a single category called cognitive information – problem-solving and decision-making. IMPRINT also places reading and writing into the communication category.

Table 5.3 Taxons and their definition from O'Brien and IMPRINT

Taxons	Definitions
Perception-Vision	Using the eyes to identify or discriminate objects or information.
Cognitive-Numerical Analysis	Performing arithmetical or mathematical calculations.
Cognition-Information Processing and Problem-Solving	Interpreting technical information, classifying objects into categories, troubleshooting or identifying the cause or source of an existing problem or failure, planning or developing a set of procedures for performing future actions, and selecting the "best" course of action from a set of multiple alternatives.
Fine Motor-Discrete	A set of discrete actions performed in a predetermined sequence. These actions largely involve movement of the hands, arms, or feet and require little physical effort.
Fine Motor-Continuous	A set of actions that are performed continuously. These actions include the continuous actions needed to keep a system on a specified path (e.g., piloting, driving); aim a device at a target, either by pointing the device directly or by moving a cursor or other control device; or align two objects with one another by continuously moving one or more of the objects until they are properly aligned.
Gross Motor-Heavy	Actions involving extensive physical effort or exertion such as lifting an object, moving it from one point to another, and lowering it; lifting and/or lowering an object and unloading or releasing it; and using a wrench or other tool to tighten or loosen a screw, bolt, or other fastener.
Gross Motor-Light	Actions involving the entire body that do not require extensive physical effort.
Communication-Reading and Writing	Reading text or numbers off a display or sheet of paper or writing with a pen or pencil.
Communication-Oral	Talking or listening to another person; can involve face-to-face or radio or phone communication.

Table 5.4 presents the three taxonomies. There is considerable commonality between the performance abilities identified in NUREG/CR-5680 Volume 2, the taxons used in IMPRINT, and the macrocognitive functions identified in NUREG-2114 (ARL, 2017; Echeverria et al., 1994; USNRC, 2016b). The performance abilities, the taxons, and the macrocognitive functions associated with task performance present a number of parallel concepts about the important attributes of tasks and their performance.

There are, however, differences in the taxonomies. The abilities framework in NUREG/CR-5680 (Echeverria et al., 1994) implies attention to individual differences and explicitly lists mood and comfort, both of which were explicitly excluded from the scope of this project. Given its focus on cognition, the macrocognitive functions framework of NUREG-2114 (USNRC, 2016b) does not include physical motor skills beyond the neurophysiological aspects of action that lead to errors of execution. As noted above, the MAs that are the subject of this report include more extensive physical activities than the human actions that are performed in an NPP main control room and

Table 5.4 Comparison of taxonomies from three sources

Performance Abilities and Measures from NUREG/CR-5680 Vol 2	Taxons from O'Brien and IMPRINT (Workload composition)	Macrocognitive Functions from Cognitive Model presented in NUREG-2114
Attention (Memory, vigilance, switching)		**Detecting and Noticing** (Sensation, perception, and attention)
Vision (Acuity, threshold perception, memory) **Perception** (Pattern recognition, visual recognition)	**Visual** (Pattern recognition and Discrimination)	
Cognitive Functions (Reading arithmetic and reasoning)	**Cognitive-Numerical Analysis** (Arithmetic or mathematic) **Cognitive Information – Problem-Solving and Decision Making** (Interpreting, classifying, identifying, planning and selecting a course of action)	**Understanding and Sensemaking** (Understanding, evaluating, hypothesizing, diagnosing, and integrating) **Decision-Making** (Goal setting, planning, replanning and adapting, evaluating options, and selection)
Psychomotor Skill (Simple and choice reaction time, coordination, tracking) **Manual Dexterity** (One hold test, flexibility)	**Fine Motor – Discrete** (Sequence of movements requiring little physical effort) **Fine Motor – Continuous** (Such as aligning, driving, or piloting) **Gross Motor – Heavy** (Extensive physical effort such as carrying, loading, lifting, lowering, torqueing and pulling) **Gross Motor Light** (Whole body without extensive physical effort)	**Action** (Physical implementation, neurophysiological function)
	Communication (read & write) **Communication – Oral** (In-person or electronic)	**Teamwork** (Coordination, communication & cooperation, crew interaction, & command & control)
Mood and Comfort (Annoyance, sense of well-being)		
Echeverria et al., 1994	*ARL, 2017; O'Brien et al., 1992*	*USNRC, 2016b*

are the focus of the (NUREG-2114, USNRC, 2016b) approach. The taxonomy of IMPRINT does not specifically identify attention but does specifically call out cognitive-numerical analysis. It also collapses other cognitive processes into a single category called cognitive information – problem-solving and decision-making. IMPRINT also places reading and writing into the communication category.

5.2.4 The Performance Demand Taxonomy

Based on consideration of the purposes of this project, the type of human actions being addressed, the nature of the environmental conditions, and the variables addressed in the human performance research literature, the research team adopted a taxonomy that combines human abilities and task requirements, which it calls performance demands. The taxonomy reflects the macrocognitive framework developed in NUREG-2114 (USNRC, 2016b) in that it recognizes the overlap among functions and their iterative, nonlinear nature. It is also informed by the emphasis in NUREG-2114 (USNRC, 2016b) on mechanisms. However, it modified the taxonomy presented in NUREG-2114 to reflect the less complex, less proceduralized, and the more actively physical nature of the MAs associated with flood protection and mitigation (USNRC, 2016b). The taxonomy adopted for this project, therefore, is not limited to cognitive functions, but includes neurophysiological and physical functions as well. In addition, as discussed above, it is designed to support the assessment of impacts on performance time for the reasons discussed above in section 5.1. The research team applied the term “performance demands” to this taxonomy in order to reflect its joint consideration of effects on human abilities and the demands imposed by task performance and to avoid confusion with the theories and terminologies associated with other taxonomies. The taxonomy of performance demands is shown in Table 5.5.

Based on this taxonomy, the following nine performance demands (with their corresponding component aspects listed in Table 5.5) are used in the rest of this report:

1. Detecting and noticing
2. Understanding
3. Decision-making
4. Action – fine motor
5. Action – gross motor
6. Action – other neurophysiological functions
7. Teamwork – reading and writing
8. Teamwork – oral communication
9. Teamwork – crew interaction.

Table 5.5 Taxonomy of performance demands

Performance Demands	Definition
Detecting and Noticing	Attention, memory, vigilance, switching[(a)], acuity, perception and threshold perception Sensation and visual recognition
Understanding	Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating
Decision-making	Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options
Action	Fine motor skills – discrete and motor continuous, and manual dexterity Gross motor skills – heavy and light Other neurophysiological functions
Teamwork	Reading and writing In-person and electronic oral communication Cooperation, crew interaction, and command and control.

(a) Switching is defined as switching from one task to another.

6 DECOMPOSITION OF MANUAL ACTIONS AND GENERALIZATION

The objective of the decomposition described in thisa chapter is to illustrate a process that analysts could use to characterize MAs at a level of specificity that allows application of the information derived from the research literature review. Lacking site-specific information about plant layout or equipment, the results of the decomposition process presented in this chapter should be viewed as a first approximation of the types of activities that make up the manual actions (MAs) and should not be interpreted as a complete or accurate list. Three decomposition examples are provided to illustrate how analysts could implement the approach and some of the specific steps they would perform.

The last section describes how grouping specific actions (SAs) that have similar performance demand profiles[1] could reduce the level of effort required for assessments conducted using this approach. The SAs thus identified into a set of generalized actions (GAs), allows the effects of environmental conditions (ECs) on an MA to be examined at a finer level of granularity and in a site-independent manner. It also discusses the possibility that the performance demand requirements of some subtasks and tasks may be sufficiently clear and affected by the prevailing ECs in such a way that tasks or subtasks could serve as the unit of analysis. It then discusses the basis for characterizing actions in terms of their performance demand profiles.

6.1 Purpose and Approach

The MAs identified through the review process described in Chapter 3 are high-level activities. Consequently, they are often complex, consisting of multiple, quite diverse tasks and subtasks that involve sequential movements and a combination of motor and cognitive functions and processes. They often involve tasks and subtasks that take place at more than one location, require travel from one location to another, and use varying levels of automation and/or types of tools or equipment. To identify how ECs affect the performance of MAs associated with flood protection and mitigation, the research team designed a process for decomposing the MAs into their component lower-level actions. This process generally follows the task analysis approach used in human performance applications. This decomposition provides the basis for characterizing those activities in terms of their performance demands and associating them with the ECs that might affect their performance.

The research team applied a simplified hierarchical task analytic approach (Kirwan & Ainsworth, 1992; Preece et al., 1994) to decompose the MAs into progressively lower-level activities: tasks, subtasks, and specific actions. This hierarchical decomposition approach (Figure 6.1) helps address the complexity of MAs and provides documentation of the set of activities that compose the MA. Tasks consist of the actions required or believed to be necessary for an individual or team of individuals to achieve a predetermined system goal, using appropriate devices as needed. A subtask is a lower-level task upon which successful performance of the task relies. Tasks may contain no subtasks or multiple subtasks. Tasks and subtasks can be further decomposed into even lower-level actions, termed specific actions (SAs). The main characteristic of an SA is its link to specific human actions that require only a few performance demands.[2] Task decomposition used in human reliability analysis (HRA), especially in nuclear

[1] The performance demand profile of an SA or a GA is defined by the relative contributions of the performance demands required to perform the action.

[2] Note that SAs obtained from decomposing a particular site's MA would contain site-specific information—e.g., as part of the MA, an individual must walk a particular distance on the given site under unsheltered conditions.

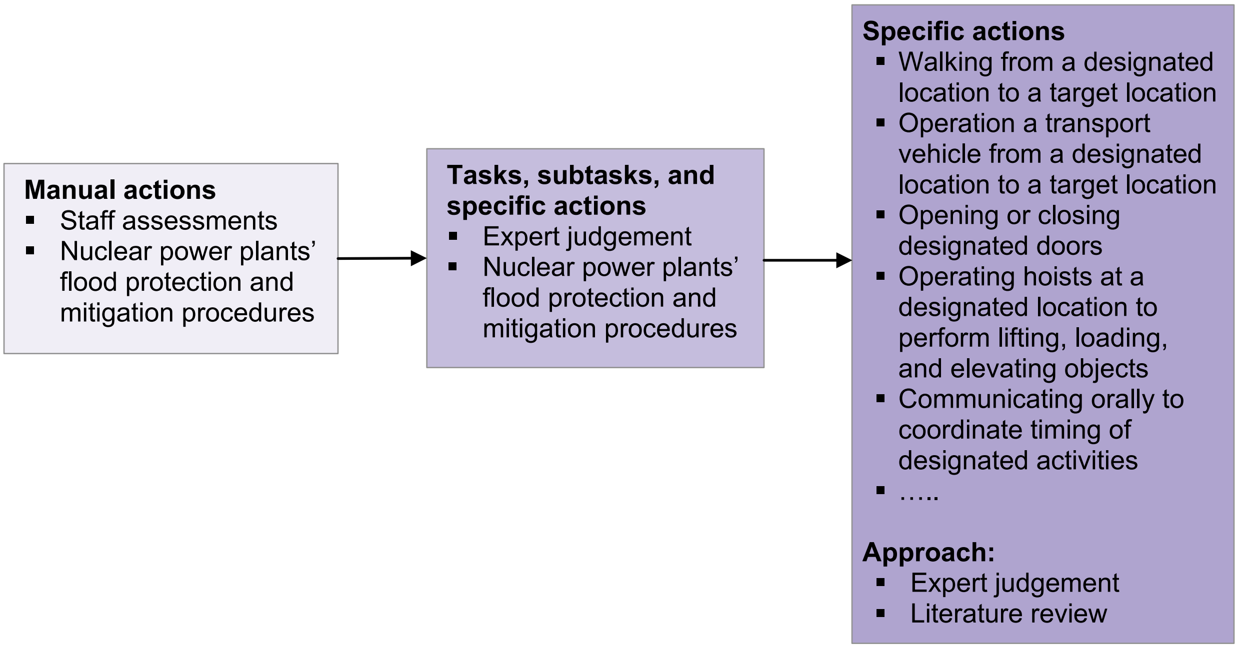

Figure 6.1 Decomposition of flood protection and mitigation manual actions

power plant (NPP) safety studies, often helps identify potential errors and estimate failure probabilities in risk analyses (NUREG/CR-2254, Bell & Swain, 1983; NUREG/CR-3371-Vol. 1, Burgy et al., 1983; Itoh et al., 1990; Smidts et al., 1997). In this instance, the immediate goal is not to estimate individual errors, failure probabilities, or improve individual performance, although it could contribute to those goals. The current objective is to gain a better understanding of the kinds of tasks, subtasks, and SAs required to complete the MAs in order to support the systematic examination of ECs' impacts on the types of activities required for flood protection and mitigation.

6.2 Decomposition to Tasks, Subtasks, and Specific Actions: Clarifying Aspects of the Manual Actions

Drawing from research on human factors and ergonomics, we use a number of terms to facilitate discussion of the proposed decomposition approach. MAs were previously defined as a distinct group of tasks performed outside the main control room (MCR) that require human action. The MAs in Figure 6.1 represent the MAs associated with flood protection and mitigation that are salient and typical across NPPs. As described in Chapter 3, the team developed a set of typical MAs by reviewing a large number of NRC staff assessments and five plant-specific flood protection and mitigation procedures.

Equipped with an understanding of which MAs might be required at NPPs in response to external flooding, the research team decomposed a few selected MAs into tasks and subtasks to illustrate the process and the types of tasks and subtasks that might be undertaken before and during flooding events. Information for this decomposition exercise was limited to available reference documents and best professional judgment. Additional analysis and consultation with NPP staff that perform flood protection and mitigation activities would be needed in a full, site-specific analysis to clarify the interdependencies among the MAs, tasks, and subtasks, and to establish nominal performance times and error types and rates for them. It is the research team's view that a hierarchical task analysis tool with capabilities similar to those in IMPRINT could be used to develop this information.

In the current research context, a task, subtask, or SA will typically consist of a mix of cognitive and manual (motor or physical) performance demands. This interplay is important because the combined demands of motor and cognitive components affect the speed and reliability of task performance (Bedny et al., 2014). A task, subtask, or SA is thus construed as logically organized cognitive and motor components (performance demands) undertaken to successfully complete the MA. The immediate goal of the proposed decomposition of MAs is to provide a clearer articulation of the tasks, subtasks, and specific actions required to complete an MA, which can then serve as the basis for the systematic examination of the impact of ECs on the performance of these tasks and actions[3].

In general, there is flexibility in task decomposition. Consequently, tasks can be decomposed to varying levels of detail (Annett, 2003). The following factors helped determine the appropriate level of task decomposition for this project:

- The level of detail should reflect the scope and depth of the available pertinent information, expert knowledge, and procedures. More detailed information will likely support decomposition of an MA to a finer level of detail. Lack of information can significantly restrict the extent to which an MA can be decomposed.
- The level of detail should be balanced against its associated cost. Annett and Duncan (1967) proposed a P*C criterion to determine the optimal level of task decomposition. In the context of HRA, P represents the probability of error at a particular level of decomposition and C represents the cost of inadequate performance at that level. If one of the two factors are low, the need for further decomposition diminishes. This project's initial decomposition attempt decomposed an MA into the basic units of human behavior. However, this level of fine detail was determined to be excessively burdensome, without value added, and lacked sufficient return on investment to justify the level of effort. Therefore, a slightly coarser unit of analysis (i.e., SA) was used to make the decomposition more tractable without compromising its analytical relevance and usefulness.
- The level of detail should be consistent with that of the model into which the task analysis feeds, based on the judgment of the modeler(s).

For a probabilistic risk assessment (PRA), Bell and Swain (1983) stated the level of detail necessary in a task analysis and the amount of information recorded should reflect the level of detail (qualitative or quantitative) of the PRA and are obviously determined judgmentally. The guiding rule for this determination is that one should be able at a later date (perhaps when the results of the HRA are compared to those from another analysis) to recapitulate the rationale for the HEP (Human Error Probability) estimates that were used in the analysis. Although the current project is not part of a probabilistic analysis effort, it is nonetheless useful to consider the underlying modeling utility that the decomposition can potentially offer to HRA performed in support of a PRA.

[3] Hierarchical Task Analysis is typically conducted as one of the preparatory steps in identifying how human errors would affect plant status and safety. Additional information about the consequences of failure to complete an MA (or its component tasks, subtasks, or SAs) and the characterization of human failure events would need to be developed for this assessment and were outside the scope of this project.

6.3 Illustration of Decomposition to Tasks, Subtasks, and Specific Actions

Three decomposition examples were produced using the approach discussed in the previous section. Five specific NPP flood protection and mitigation procedures were available to the research team, to review, thus, the decomposition outcome presented in this section is a first approximation with no external validation. It should be taken as a heuristic tool to help readers understand how decomposition was done in this study. In the future, subject matter experts could be invited to review and provide confidence in the decomposition results.

MAs were decomposed through group discussion and consensus building. The research team, representing expertise in PRA, HRA, human factors, industrial hygiene, hydrology and environmental science, assembled available information about the MAs and followed a preliminary set of criteria to guide the decomposition and characterization of an MA into tasks, subtasks, and SAs. The research team did not establish clear criteria for distinguishing between the different levels of decomposition (i.e., task, subtask, SA), but expects those criteria to evolve and be refined as MAs are decomposed in consultation with the NPP staff who has experience in performing them. The research team used the following to select the MAs to decompose:

- The MA should have a high level of complexity and thus provide an appropriate illustration of the decomposition approach.
- The MA should be salient in flood protection at multiple NPPs.
- The research team should have access to detailed information about the MA, either from prior knowledge or access to reference documents.

The MAs selected for decomposition were to (1) install a portable pump, (2) install flood barriers on exterior intake structure walls, and (3) build a sandbag berm around the service water strainer pit. In decomposing the three selected MAs into tasks, subtasks and SAs, the research team applied the following preliminary criteria:

- Each progressive level should be associated with accomplishing an objective of the level above it (i.e., a step in a procedure that is associated with a goal).
- The lowest level of decomposition should allow assignment to a single sheltered category (i.e., sheltered, semi-sheltered, unsheltered).
- The lowest level of decomposition should allow assignment to a single location category (i.e., fixed, semi-fixed, or variable).

The following examples present the MAs and their tasks, from which a task is selected to be decomposed into subtasks, from which a subtask is selected to be decomposed into SAs. Though hypothetical, the examples are based on an actual MA for an NPP in the United States.

6.3.1 Decomposition Example 1 – Install a Portable Pump

One type of MA, identified by several NPPs as an action that would be performed in response to an external flooding event, is the setup and operation of portable pumps. To illustrate how an MA might be decomposed into SAs, the research team developed an example: “Install a portable diesel pump.” This MA was selected because it is complex, has several and varied subtasks, and would be performed at both sheltered and unsheltered locations. The MA was divided into the following tasks:

1. **Clear Debris**. This task involves clearing debris from the haul path between the reactor building where the pump will be installed and the locations where the pump, fittings, and hose are stored.
2. **Load and Unload the Portable Pump.** This task involves driving to the location where the portable diesel driven pump is located; loading the pump; driving to the location where the pump's fittings and hoses are located; loading the equipment; transporting the pump, fittings, and hoses to the reactor building; and unloading the equipment.
3. **Set Up the Portable Pump.** This task consists of connecting fittings, adapters, and hoses from the portable diesel driven pump to a plant cooling system; staging fuel; fueling the pump; and aligning valves.
4. **Operate the Portable Pump.** This task consists of turning on the pump, controlling it to needed operating parameters, and monitoring control.

Among the tasks, "clear debris" was the most exposed to ECs (i.e., unsheltered) and "set up the portable pump" and "operate the portable pump" were performed inside a reactor building (i.e., sheltered). Task 2, "load and unload the portable pump," was further decomposed into subtasks and SAs (Table 6.1).

Table 6.1 Illustration of decomposing load and unload portable pump

Task 2 – Load and Unload Portable Pump			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 2.1 – Drive Transport Vehicle to Equipment Storage Building			
Walk to the transport vehicle location from reactor building	Unsheltered	Variable	Transport vehicle is located away from reactor building and equipment storage building
Enter the transport vehicle	Unsheltered	Fixed	Personnel must unlock and open the vehicle.
Operate the transport vehicle to move it from its location to the equipment storage building	Semi-sheltered	Variable	This involves driving to a location away from the reactor buildings. Considered semi-sheltered because weather could affect visibility and hearing.
Exit the transport vehicle	Semi-sheltered	Fixed	
Open the equipment storage building door (i.e., high bay door of the storag the building)	Unsheltered	Fixed	This task involves unlocking the door and operating the door mechanism.
Enter the transport vehicle	Semi-sheltered	Fixed	
Operate the transport vehicle to move it into the equipment storage building	Semi-sheltered	Variable	Involves pulling the transport vehicle into the storage facility.
Exit the vehicle	Semi-sheltered	Fixed	

Task 2 – Load and Unload Portable Pump			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 2.2 – Load Diesel Driven Pump into Transport Vehicle			
Operate the powered hoist to load the pump on the transport vehicle	Sheltered	Fixed	This task involves positioning the hoist over the load, and lifting, moving, and lowering the load into place using the hoist controls.
Perform manual work with simple equipment (i.e., secure pump on the transport vehicle)	Sheltered	Fixed	This task involves primarily physical movements, such as gripping and pulling, to apply load constraints.
Subtask 2.3 – Drive Transport Vehicle to Equipment Storage Container			
Enter the transport vehicle	Unsheltered	Fixed	Personnel must unlock and open the vehicle.
Operate the transport vehicle to move the pump from the equipment storage building to the equipment storage container location	Semi-sheltered	Variable	Includes driving the transport vehicle from the equipment storage building to the equipment storage container location. Considered semi-sheltered because weather could affect visibility and hearing.
Exit the transport vehicle	Semi-sheltered	Fixed	
Subtask 2.4 – Load Equipment from Outdoor Container on Transport Vehicle			
Open the large container door	Unsheltered	Fixed	Involves unlocking and opening the Sea-Van container.
Load equipment (i.e., hoses and fittings) on the transport vehicle	Unsheltered	Semi-fixed	Involves gathering (gripping and lifting) hoses and fittings from the storage container and loading them onto the transport vehicle. This subtask is assumed to be mostly unsheltered and to occur when opening the container.
Perform manual work with simple equipment (i.e., secure equipment onto the transport vehicle)	Unsheltered	Fixed	This task primarily involves physical movements, such as gripping and pulling, to apply load restraints.
Subtask 2.5 – Drive Transport Vehicle to Reactor Building Location Where Equipment Will Be Unloaded			
Enter the transport vehicle	Unsheltered	Fixed	Personnel must unlock and open the vehicle.
Operate the transport vehicle from the equipment storage container location to the reactor building	Semi-sheltered	Variable	Includes driving the transport vehicle from the storage container location to the reactor building where the pump will be unloaded. Considered semi-sheltered because weather could affect visibility and hearing.
Exit the transport vehicle	Semi-sheltered	Fixed	

Task 2 – Load and Unload Portable Pump			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Communicate electronically outside the reactor building (i.e., to get the high bay door open)	Semi-sheltered	Semi-fixed	Involves communication and coordination with individuals in the reactor building to have the high bay door opened.
Operate the transport vehicle to move it inside the reactor building	Semi-sheltered	Semi-fixed	Includes driving transport vehicle into the reactor building.
Exit the transport vehicle	Semi-sheltered	Fixed	
Subtask 2.6 – Unload Pump, Hoses, and Fittings from Transport Vehicle			
Operate the powered hoist to unload the pump and other equipment from the transport vehicle	Sheltered	Fixed	Involves positioning the hoist over the load, and lifting, moving, and lowering the load using the hoist controls and physical movements.

6.3.2 Decomposition Example 2 – Install Flood Barriers on Exterior Intake Structure Walls

Several NPPs identified the placement or installation of flood barriers as an MA that would be performed in preparation for an external flooding event. To illustrate how this MA might be decomposed into tasks, subtasks, and SAs, the research team decomposed an example: "Install Flood Barriers on Exterior Intake Structure Walls." This MA was selected because it is representative of MAs credited for several plants, craft labor would be involved in the construction activities, it has several and varied subtasks, and it would be performed in unsheltered and sheltered locations. This MA was divided into the following tasks:

1. **Fabricate Steel Plates**. This task involves fabricating steel plates for placement over ventilation and other openings on the walls of the intake structure of the appropriate size and with fastener holes in the correct locations.
2. **Clear Debris.** This task involves clearing debris that may have accumulated or is present in the area around the intake structure or any haul paths.
3. **Stage Steel Plates and Equipment.** This task involves transporting steel plates, fasteners, and hand tools from the shop area to locations around the outside of the intake structure.
4. **Prepare Wall Surfaces for Barrier Placement.** This task involves preparing the exterior intake structure wall by removing fixtures (e.g., vent screens) and applying sealant around openings.
5. **Fasten Barriers onto Exterior Walls**. This task consists of placing the steel plates against the intake structure exterior wall opening and fastening it into place.

Task 5, "fasten barriers onto exterior walls" was further decomposed into subtasks and SAs (Table 6.2).

Table 6.2 Illustration of decomposing fasten barriers onto exterior walls

Task 5 – Fasten Barriers onto Exterior Walls			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 5.1 – Procure a Forklift and Move It into Position to Lift the Steel Plate			
Walk from the current location of the individual performing the subtask to where the forklift is parked	Unsheltered	Variable	If a forklift is not already available from an earlier subtask in which material and equipment are staged at the intake structure, then a forklift must be procured.
Climb into the forklift	Unsheltered	Fixed	The forklift was assumed not to have an enclosed cab.
Operate the forklift from the forklift's parking location to drive to the appropriate exterior wall locations	Unsheltered	Variable	This action involves driving around the building to appropriate locations and requires a forklift operator.
Subtask 5.2 – Load Steel Plate onto Forklift			
Operate the forklift to pick up the steel plate	Unsheltered	Fixed	This task involves a skilled forklift operator using the forklift controls to lift the steel plate.
Subtask 5.3 – Place the Steel Plate Against the Opening Using the			
Operate the forklift to move the steel plate	Unsheltered	Variable	This task involves a skilled forklift operator using the forklift controls to move the steel plate to where it needs to be installed at openings.
Communicate non-electronically with other personnel to coordinate placement of steel plate on the exterior wall	Unsheltered	Variable	Involves non-electronic communication and coordination.
Operate the forklift to place the steel plates against the doors or openings on the exterior walls	Unsheltered	Semi-fixed	This task requires a forklift operator to drive the forklift and to manipulate the steel plate into position. It may also require the coordinated actions of additional personnel.
Move heavy materials manually (i.e., adjust the steel plate against the wall/door)	Unsheltered	Fixed	Requires the coordinated actions of several personnel.
Subtask 5.4 – Drill Holes into the Intake Structure and Secure Steel Plate Using Fasteners			
Use hand tools (i.e., drill holes in the exterior walls)	Unsheltered	Fixed	This task involves skilled personnel (i.e., craft labor) using hand tools to drill holes in intake structure walls for lag bolts or concrete anchors.
Use hand tools (i.e., to place lag bolts or concrete anchors in place)	Unsheltered	Fixed	This task involves skilled personnel (i.e., craft labor) using hand tools to place lag bolts or concrete anchors.

6.3.3 Decomposition Example 3 – Build a Sandbag Berm around the Service Water Strainer Pit

Another type of MA identified by several plants that would be performed in preparation for an external flooding event is the building of berms or using sandbags, curbs, or, in some instances, heavy equipment. To illustrate how this MA might be decomposed into tasks, subtasks, and SAs, the research team decomposed an example: "Build a Sandbag Berm around the Service Water Strainer Pit." This MA was selected because it is representative of MAs that are credited for several NPPs, had several and varied subparts, and would be performed in unsheltered locations. The MA was divided into the following tasks:

1. **Procure Sandbags**. This task involves obtaining sand bags from the County Emergency Operations Center.
2. **Build a Sandbag Filling Rack.** This task involves building a sandbag filling rack to hold bags open for filling the bags.
3. **Clear Debris.** This task involves clearing debris that may have accumulated or is present in the area of the sand pile, service water strainer pit, or haul path.
4. **Stage Sandbags,** Equipment, and Front-end Loader. This task involves transporting the sandbags, the sandbag filling rack, and hand tools for filling the bags to the location of the sand pile. This task also involves procuring and bringing a front-end loader to the location of the sandbags.
5. **Fill Sandbags**. This task involves filling the sandbags with a front-end loader and hand tools and loading them onto a transport vehicle.
6. **Transport Filled Sandbags to the Service Water Strainer Pit.** This task involves transporting the filled sandbags to the service water strainer pit.
7. **Place Sandbags around the Service Water Strainer Pit.** This task consists of building a 6 ft berm using sandbags around the service water strainer pit.

Task 5, "filling the sandbags," was further decomposed into subtasks and SAs (Table 6.3).

Table 6.3 Illustration of decomposing filling sandbags

Task 5 – Filling the Sandbags			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 5.1 – Procure a Front-end Loader and Move It into Position			
Walk from the current location of the individual performing the subtask to where the front-end loader is parked	Unsheltered	Variable	From an earlier task, a front-end loader has been procured and is available at the sand pile site.
Climb into front-end loader	Unsheltered	Fixed	The front-end loader was assumed not to have an enclosed cab (though some front-end loaders do have enclosed cabs).
Operate the front-end loader to position it	Unsheltered	Variable	Requires front-end loader operating experience.

Task 5 – Filling the Sandbags			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 5.2 – Procure Transport Vehicle, Operate it and Move It into Position			
Walk from the current location of the individual performing the subtask to the parking location of the transport vehicle	Unsheltered	Variable	Transport vehicle is located away from the reactor building and equipment storage building.
Enter transport vehicle	Unsheltered	Fixed	Personnel must unlock and open vehicle.
Operate the transport vehicle to move it into position	Semi-sheltered	Variable	Considered semi-sheltered and variable location because although the vehicle driver will be in the truck cab, the driver will move from one location to another.
Exit the transport vehicle	Semi-sheltered	Fixed	
Subtask 5.3 – Set Up the Sandbag Fill Rack			
Move the equipment into position (i.e., set fill rack into position at designated location)	Unsheltered	Semi-fixed	Requires two individuals to move the rack. The primary motions would be gripping and lifting.
Set up the equipment (i.e., hang the sandbags on the fill rack)	Unsheltered	Fixed	
Subtask 5.4 – Fill Bags Using Front-end Loader			
Operate the front-end loader (i.e., drive the front-end loader to the sand pile)	Unsheltered	Variable	The task involves driving the front-end loader and requires front-end loader operating experience.
Operate the front-end loader (i.e., scoop sand into the loader bucket)	Unsheltered	Semi-fixed	The task involves operating the front-end loader controls to scoop a bucket of sand. Requires front-end loader operating experience.
Operate the front-end loader (i.e., drive the front-end loader to the fill rack)	Unsheltered	Variable	
Operate the front-end loader (i.e., place sand into bags using the front-end loader bucket)	Unsheltered	Semi-fixed	This task involves dumping sand from the front-end loader bucket into the sandbags at the fill rack using the front-end loader controls. Requires front-end loader operating experience.
Subtask 5.5 – Adjust Fill Amount Using Hand Tools and Close Bag			
Use hand tools (i.e., to adjust the amount of sand in sandbags to appropriate amount)	Unsheltered	Semi-fixed	This task involves use of hand tools to level out or adjust the amount of sand in the sandbags.
Perform manual work with simple equipment (i.e., take sandbags off fill rack)	Unsheltered	Fixed	This task involves manually gripping, lifting, carrying, and moving filled sandbags off fill rack.
Perform manual work with simple equipment (i.e., tie off the sandbags)	Unsheltered	Fixed	This task involves manually using the tie strings at the top of the sandbag to tie off the bag.

Task 5 – Filling the Sandbags			
Specific Actions	**Degree of Sheltering**	**Location**	**Comments**
Subtask 5.6 – Load the Filled Sandbags onto the Transport Vehicle			
Load material manually (i.e., sandbags) onto the transport vehicle	Unsheltered	Fixed	This task involves gripping, lifting, and carrying sandbags to load onto the transport vehicle.

6.4 Summary of Decomposition and Examples

The procedures in the five site-specific flood protection and mitigation examples that the research team reviewed include anticipatory actions that are typically performed well in advance of any pending external environmental threat to an NPP. The steps required to perform these anticipatory actions are laid out in written procedures, although information about sequencing or time estimation was not available to the research team. In addition to these proceduralized activities, flooding events may also require actions, which may not be proceduralized, to be taken in response to evolving situations. Given the dynamic nature of flooding events, MAs will likely include both proceduralized and non-proceduralized activities, which would need to be identified in the MA identification and decomposition process for each specific site.

The decomposition process was conducted by individuals without expert knowledge of either the MAs or the context in which they would be performed and has not been verified. The example MAs, tasks, subtasks, and SAs presented in this report are included to illustrate the type of MAs, tasks, subtasks, and SAs that might need to be performed in preparation for or in response to a flooding event, and they should be interpreted as illustrative, but not as a reliable and exhaustive inventory of MAs.

6.5 Generalization of Specific Actions and Evaluation of Performance Demands

This section describes the concept of reviewing SAs, determined from the decomposition of MAs, to identify actions that are repeated or that are very similar in order to assemble a parsimonious list of generalized actions (GAs). As shown in Table 6.4, it may be possible to create more generalized descriptions of the activities represented by the GAs that allow multiple SAs to be grouped into these generalized categories.

If this type of analysis is conducted over a large set of sites, consolidating SAs into a smaller number of GAs could reduce the level of effort needed to decompose site-specific MAs, evaluate the SAs, determine their performance demand composition, and establish how they would be affected by ECs. However, the site-specific context of the SA, including the time and location at which it takes place, can influence the ECs that would apply (as well as other factors that affect performance). Consequently, the method must provide the ability to reposition the GAs back into their task hierarchy and account for site context.

Depending on plant design and the adopted flood protection and mitigation procedures, the list of MAs, SAs, and GAs may be quite large. Consequently, it is likely that a preliminary evaluation to identify the MAs, SAs, and GAs warranting quantitative assessment under different potential ECs could save considerable time and effort. In its review of plant-specific flood protection and mitigation procedures, the research team also found that a number of tasks and subtasks are performed at multiple sites. Therefore, the decomposition into GAs may not be necessary, but in the case of differing SAs across plants, the GA concept could reduce the effort required to decompose MAs at different sites.

To illustrate the review and aggregate concept, the research team aggregated the SAs identified from the small subset of MAs discussed above into a preliminary example set of GAs, as shown in Table 6.4. In this example, SAs are decomposed into a set of GAs whose performance demand profiles are sufficiently similar that an EC would affect them similarly. The decomposition exercise revealed that the GAs could be performed across the range of sheltered conditions (i.e., sheltered, semi-sheltered, or unsheltered) and at fixed, semi-fixed, or variable locations, factors that analysts would need to consider in site-specific assessments.

It is worth noting that the appropriateness and validity of the decomposition of MAs may be constrained by the availability of authoritative information (e.g., detailed plant flood procedures) and subject matter experts (e.g., individuals who have experience in performing these actions). Method validation and expert feedback should be sought to (1) improve the results and the outcome of the task decomposition effort, and (2) pave the way for the integration between GA characteristics and MA performance in the context of varying ECs.

6.5.1 Characterization of Generalized Actions in Terms of Performance Demands

In the proposed impact assessment approach, ECs affect human performance through their impact on the performance demands of the task being performed. Consequently, an analyst would assess the impact of an EC on the performance of an MA by first analyzing how the EC affects the performance demands that make up the GA. MAs, tasks, subtasks, and SAs call upon and impose a variety of performance demands on those performing them. For example:

- Loading material onto a transport vehicle imposes demands primarily on gross motor skills and to a smaller extent on detecting and noticing and decision-making.
- Operating a heavy vehicle calls on motor and cognitive skills.
- Communication and coordination impose demands on cognitive and communication skills.

Other SAs (e.g., energizing a jumper cable) call upon fine motor skills (e.g., finger movements at a bus panel) as well as cognitive skills.
Although a single individual may perform some actions, team communication is likely to be especially important in performing the actions undertaken for flood protection and mitigation. Consequently, the MAs will include actions with high communication performance demands. The research literature on human performance and task and system design provides a long history of methods to understand the performance demands that different tasks impose. Methods such as task analysis (Kirwan & Ainsworth, 1992; Wheeler & Toquam, 1991), cognitive task analysis (Crandall et al., 2006; Kieras & Meyer, 2000; Militello & Hutton, 1998; Pirolli & Card, 2005; Schraagen et al., 2000), verbal protocol analysis (Tolbert & Bittner Jr., 1991; Triggs et al., 1990), time-motion studies (Maynard et al., 1948; Quick et al., 1945), human performance and task taxonomy analysis (Fleishman et al., 1984; Gilbreth & Gilbreth, 1924) and operational sequence diagraming (Kurke, 1961; Nakanishi & Okada, 2012) have been used to characterize the demands imposed by tasks of different types and the human abilities needed to perform them. In the course of this historical work, including work supporting ARL, information has been developed about the performance demand profiles of many specific activities.

However, if an analyst is starting to develop a performance demand profile of an action, one approach is to proceed sequentially through the main demands of the action as it would be performed. Task analysis strategies can be applied to characterize actions. GAs can be defined

Table 6.4 Example generalization of specific actions

Specific Actions from Decomposition Exercise	Preliminary Example of Generalized Actions (GAs)
• Walk to transport vehicle location from reactor building (Subtask 2.1) • Walk from current location of individual performing the subtask to where forklift is parked (Subtask 5.1)	Walk from one location to a target destination (e.g., to a vehicle).
• Enter/exit transport vehicle (Subtasks 2.1, 2.3, 2.5) • Climb into the forklift (Subtask 5.1)	Enter or exit a vehicle or light or heavy motorized equipment.
• Operate the transport vehicle (Subtasks 2.1, 2.3, 2.5)	Operate/drive a transport vehicle from one location to a target destination.
• Open high bay door of storage building (Subtask 2.1) • Open large container door (Subtask 2.4)	Manually move a building or large container door into a target position (e.g., open or close).
• Operate the powered hoist to load or unload equipment (Subtask 2.2, 2.6)	Operate a powered hoist to move (e.g., load, unload, or elevate) objects from one location to a target destination.
• Manually secure pump onto transport vehicle (Subtask 2.2) • Manually secure equipment onto transport vehicle (Subtask 2.4)	Manually move a light weight object from one location to a target destination.
• Manually adjust heavy steel plate against wall/door (Subtask 5.3)	Manually move heavy objects from one location to a target destination.
• Using simple equipment, manually secure pump onto transport vehicle (Subtask 2.2) • Using simple equipment, manually secure equipment onto transport vehicle (Subtask 2.4)	Work manually with simple equipment to fasten/secure items in a target location.
• Operate forklift from forklift's parking location to drive to appropriate exterior wall locations (Subtask 5.1) • Operate forklift to pick up/move steel plates (Subtask 5.2, 5.3) • Operate forklift to place steel plates against doors or openings on exterior walls (Subtask 5.3)	Operate a forklift to pick up, move, or place objects from one location to a target destination.
• Electronically communicate to get reactor building high bay door open (Subtask 2.5)	Communicate electronically to direct the actions of a colleague.
• Non-electronically communicate with other personnel to coordinate placement of the steel plate on exterior wall (Subtask 5.3)	Communicate non-electronically to coordinate actions with a colleague.
• Use hand tools (i.e., drill holes in the exterior walls) (Subtask 5.4) • Use hand tools (i.e., to place lag bolts or concrete anchors in place) (Subtask 5.4)	Work manually with hand tools to drill holes or place/fix items in a target location.

with the objective to develop GAs whose performance demand profile (i.e. the nature and proportion of performance demands) remain stable (i.e. unaffected) across changing ECs[4] For example, the analyst might initially start by generalizing a site-specific SA: “unsheltered walking 400 m from sheltered point A over flat ground to sheltered point B under shirtsleeve, daylight conditions.” The analyst might recast the SA into three GAs that would eliminate the site-specific context (i.e., degree of sheltering [unsheltered to sheltered], distance walked [400 m], topography [flat ground], clothing [shirtsleeves], and lighting [daylight]). These GAs could be (1) assess the ECs in effect in the unsheltered area, (2) put on EC appropriate gear (always available along exit hallway) and (3) identify and execute the planned route. The first and second actions appear to have similar performance demand profiles when performed in the presence of differing ECs (albeit each taking relatively different durations to perform). However, the performance demand profile of the third could vary considerably under different ECs. For example, route assessment might take a couple of seconds in daylight with misting rain, but several minutes if the unsheltered area were inundated with moving water. Under these same EC alternatives, actual walking time might be slowed only by a factor of 2 or so. Consequently, the analyst might look at the number and sequence of performance demands required and break compound SAs into two or more GAs, each with controlling performance demands. This approach, though requiring further applied research to fully verify, parallels the development of similar approaches in previous human performance modeling efforts (ARL, 2017; Glenn, 1988; Kieras, 2002; Pew, 2007)[5].

Table 6.5 illustrates, notionally, the different performance demand profiles of two hypothetical GAs (i.e., different perception, cognition, motor skill, and teamwork demand). By taking into account the performance demand profile of a GA (i.e., the nature and relative weights or proportions of performance demands as illustrated in Table 6.5), the analyst can assess how the effects of an EC on the performance demands would change the performance of the GA, compared to baseline conditions. The impacts from each of the ECs would then be aggregated to estimate the overall impact on the GA[6]. Table 6.6 illustrates this approach. One system for recording performance demand profiles of GAs and quantitatively estimating the effects of ECs on performance demands, based on research data concerning EC effects, is the IMPRINT software. Chapter 8 discusses the extent to which published research literature provides a basis for establishing impact levels on the performance demands for the ECs that might prevail during external flooding events. Further discussion about how the impact of ECs on GAs can be aggregated back up to the level of an MA is presented in Chapter 9.

6.6 Application of the Assessment Method at the Level of Tasks and Manual Actions

The taxonomy of performance demands creates an important bridge to enable a quantitative assessment of the impacts of ECs on human performance. The performance demands address the intersection of MAs and ECs. Given the focus of this project on understanding and highlighting how and to what extent the prevailing ECs impact human performance, the

[4] It is important to note that it is the performance demand profile that remains stable across ECs; impacts would obviously vary, depending upon the EC.

[5] This approach arguably also parallels the generalization across NPP sites of sensory and cognitive underpinnings of personnel actions (see NUREG-2114, USNRC, 2016b).

[6] Impacts from combinations of ECs are estimated using one of several approaches—additive, multiplicative, and power functions. The team did not find justifications for using one over the other, although ARL notes that typically, each additional EC has a less than additive effect, if the analysis starts with the most impactful EC (Comperatore et al., 2015).

Table 6.5 Notional performance demand profiles of hypothetical generalized actions

Performance Demands	Operate a transport vehicle from a designated location to a target destination (% Contribution)	Manually lift and move designated heavy materials or equipment from a designated location to a target destination (% Contribution)
Detecting and noticing	40	20
Understanding	-	-
Decision-making	-	-
Action – fine motor	30	20
Action – gross motor	30	60
Action – other neurophysiological functions	-	-
Teamwork – reading and writing	-	-
Teamwork – oral communication	-	-
Teamwork – crew interaction	-	-

Table 6.6 Aggregating the impact of environmental conditions on generalized actions' performance demands

GAs	Performance Demands	EC1	EC2	EC3	EC4	Total Impact on GAs
		Degree of Impact				
GA1	Performance Demand 1	High	Medium	High	Low	Impact 1[(a)]
	Performance Demand 2	Low	Medium	Medium	Medium	
	Performance Demand 3	Low	Medium	Medium	High	
GA2	Performance Demand 1	Low	Low	Low	Low	Impact 2[(a)]
	Performance Demand 2	High	Low	Low	Low	
	Performance Demand 3	Low	Medium	Low	Medium	
(a) Weighted impact of ECs based on performance demand contributions to a GA (Table 6.5)						

research team concluded that addressing these effects at the level of SAs or GAs would be illustrative. It is evident from Chapters 3 through 6 that this approach requires considerable analytic effort. Consequently, it may be desirable to accomplish the assessment at a higher level of aggregation, if that would provide an adequate level of precision and reliability. Future studies could use the information provided in this report to evaluate the feasibility of a higher-level assessment approach. Analysts could do this by selecting a few MAs, along with their tasks, that represent the variability in the degree of shelter and fixed/variable location and examining how the results compare if the method is applied at the SA, task, and MA levels. This would require establishing baseline times (and perhaps error rates) for each level/component of the selected MAs.

7 OVERALL CONCEPTUAL FRAMEWORK AND APPLICATION

This chapter presents the overall conceptual framework developed by the research team for an assessment of the impacts of flooding events on the performance of manual actions (MAs) related to flood protection and mitigation. It focuses on impacts from the environmental conditions (ECs) that might accompany such flooding events. Consequently, it does not address other performance shaping factors (PSFs) that may also need to be addressed when assessing the performance of flood protection and mitigation procedures (e.g., crew composition, training, nature of the equipment, procedure quality).

7.1 Framework Overview

A framework is a conceptual structure that identifies the key components and relationships required for development of an analytical approach or model. In this research, the approach, or model, addresses the assessment of the effects of the environment on human actions. Such a framework also guides the identification of the concepts and data required for site-specific applications.

This chapter describes a conceptual framework that identifies the underlying concepts and information needed to assess the impact of ECs that might be associated with an external flooding event at U.S. nuclear power plant (NPP) sites and the potential impacts of ECs on the performance of those MAs.

Figure 7.1 presents the framework diagram which has six basic elements. The framework can be extended to include generalized actions (GAs) which are indicated by “GA” and were introduced in Section 6.5 and are discussed below in Sections 7.1.1 and 7.2.2.1 The elements are:

1. identification of flood causing mechanisms and characterization of potential ECs including secondary and co-occurring ECs;
2. characterization of MAs, the tasks, subtasks, and specific actions (SAs);
    - 2.1. GA 2.1 The generalization of SAs into a smaller set of site-independent generalized actions;
3. development of the performance demand profile of SAs;
    - 3.1. GA 3 development of the performance demand profiles of GAs;
    - 3.2. GA 3.1 characterization of site-specific SAs by combining site-specific task context with GAs;
4. review of the research literature to identify what is known about how ECs affect performance demands and human performance;
5. characterization of potential impacts of ECs on site-specific SAs based on performance demand profiles; and
6. aggregation of the impacts of ECs from site-specific SAs to subtasks to tasks to MAs.

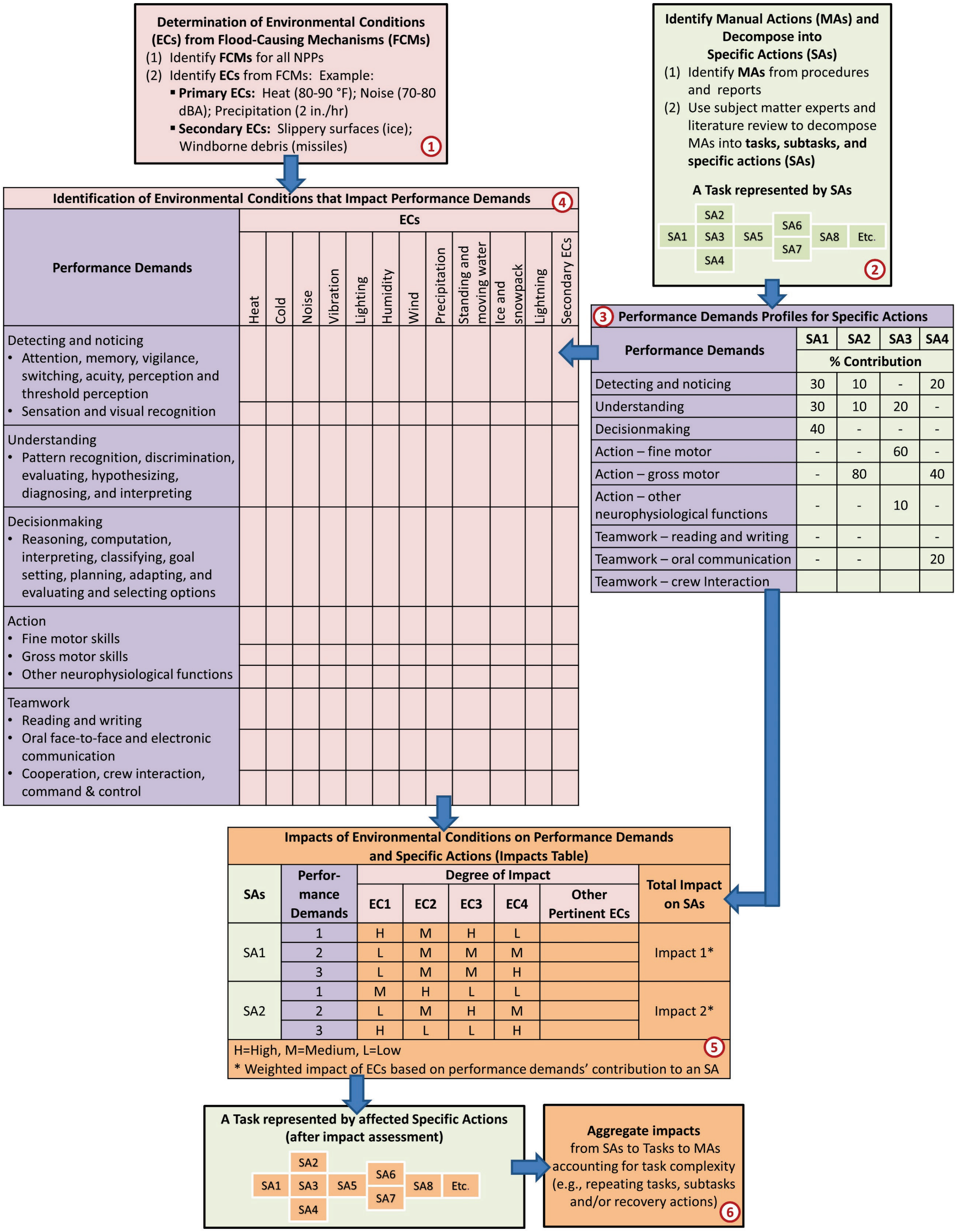

Figure 7.1 Proposed framework diagram. Intended for assessing impacts of environmental conditions on flood protection and mitigation manual actions.

The first element (Element 1), presented on the top left of the diagram, shows that the analyst would need to identify ECs from flood causing mechanisms (FCMs). The element also shows examples of secondary ECs that occur in the presence of primary ECs.

The second element (Element 2), presented in the upper right-hand corner of the diagram shows that analysts must identify MAs and break them down (i.e., decompose them) into finer elements, in this case tasks, subtasks, and specific actions. Near the end of the framework, the diagram also shows how specific actions can be recombined to form higher-level functions—in this example tasks, and MAs.

The second panel in the right column (Element 3) shows the SA-performance demands table. The table shows examples of the performance demand profiles for hypothetical SAs, in terms of the proportional contribution of the performance demand to -SA performance.

The ECs-performance demands table in the left center of the diagram (Element 4) shows that the intersection between each EC and each performance demand should be considered to distinguish between those that are and are not pertinent to the assessment at hand. The 11 ECs addressed in this report are listed, along with a column for secondary ECs. Check marks in the cells would indicate an EC-performance demand interaction, in that research indicates that a particular EC could affect those performance demands. Chapter 8 describes in more detail how ECs affect performance demands and thereby impact the performance of SAs, subtasks, tasks, and MAs whose profiles include those performance demands.

The impacts table (Element 5) near the bottom center of the diagram shows that the impacts of ECs on site-specific SAs can be determined using the insights gained from the review of the research literature. Those insights of ECs effect on performance demands can be used to assess how an EC would affect an SA. This could be done by weighting the ECs' impacts on the performance of the SA in proportion to the ECs' impacts on the constituent performance demands, considering the performance demand profile of the SA. Impacts of ECs on SAs could be expressed as modifications (usually an increase under the ECs being considered) of the baseline performance time and/or the probability of failure. Finally, in the bottom right panel (element 6), impacts for constituent site-specific SAs are aggregated to subtask, task, and MA levels.

7.1.1 Framework with Generalized Actions

To facilitate certain analyses, the framework can be extended to use generalized actions as shown in Figure 7.2 and described in Section 6.5 . The generalized action elements (Elements GA 2.1, GA 3, GA 3.1) take place between elements 2 and 5 in the specific action framework in Figure 7.1. The specific actions from the decomposition process are assembled, reviewed, and aggregated into generalized actions, based on similarity in their performance demand profiles.

Element GA 2.1 on the right-hand side of the diagram, following element 2, describes how generalized actions are identified from specific actions.

Similar to the regular framework, the GA-performance demands table (Element GA 3) shows examples of the performance demand profiles for hypothetical GAs, in terms of the proportional contribution of the performance demand to generalized action

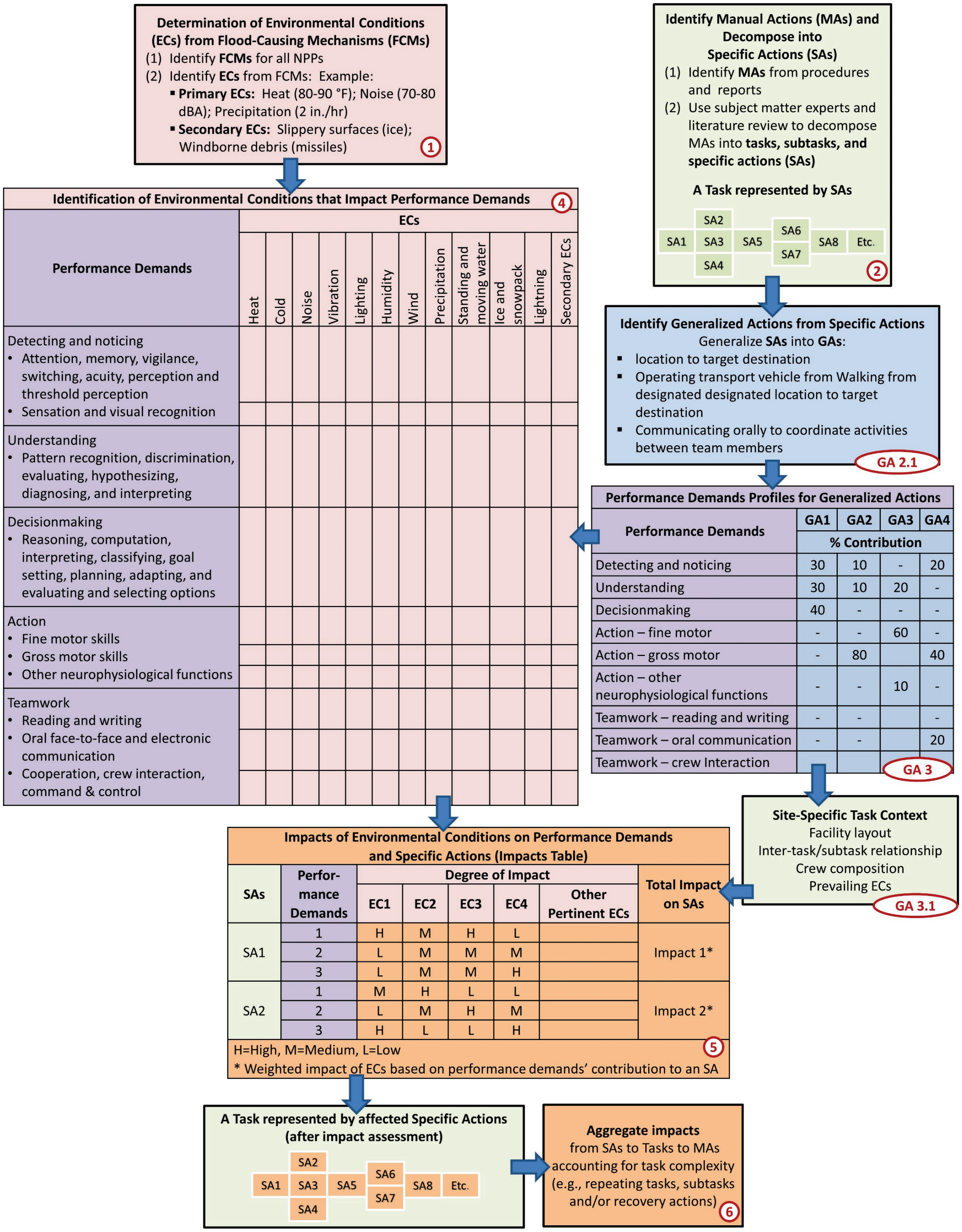

Figure 7.2 Proposed framework diagram using generalized actions. Intended for assessing impacts of environmental conditions on flood protection and mitigation manual actions.

The site-specific task panel (Element GA 3.1) on the bottom of the right column of the diagram indicates that site-independent GAs can be combined with site-specific information (e.g., facility layout, inter-task/subtask relationships, failure consequences at task/subtask level and any attempted recovery actions, crew composition, and prevailing ECs at the location and at during the time the actions are performed) to obtain site-specific SAs.

7.2 Components of the Framework

7.2.1 Characterization of Pertinent Flood Causing Mechanisms and Environmental Conditions (Element 1)

Chapter 2.2 identifies a set of possible external flood causing mechanisms and associated environmental conditions that require characterization in sufficient detail to identify the range of possible ECs that can affect human performance of MAs. The environmental conditions of concern in this project include heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning. These ECs can create or be accompanied by secondary ECs (e.g., slippery surfaces, windborne debris, and condensation on glass surfaces). Flooding events will likely entail a combination of ECs. An EC is a particular state (e.g., air temperature of 95°F would be an EC for heat, air temperature of 30°F would be an EC for cold) at the time and location an MA is being performed. Chapter 9 provides a description of the process for identifying and characterizing ECs, including secondary ECs that impact the performance of flood protection and mitigation actions.

7.2.2 Characterization of Manual Actions and Performance Demand Profiles (Element 2)

MAs generally refer to actions taken or directed by plant staff that NPPs credit for mitigating or preventing impacts associated with an external flooding event (see Chapter 3 for a more in-depth definition and description). Example MAs relevant to flood protection and mitigation include installing sump pumps and flood barriers. Hence, although the term “manual action” may seem to refer to a set of simple movements, an MA may be much more complex. MAs typically involve a set of related tasks or a sequence of steps and often require communication and coordination among plant staff. Decomposing the MAs into their simpler elements (e.g., tasks, subtasks, and specific actions) provides a clearer intersection with the human performance research literature, which is often focused on very simple actions and performance demands. Specific actions can be characterized in terms of the combination of performance demands that must be met for their completion, implementing a useful approach described in this report that human performance is affected by ECs via their adverse effects on performance demands. The decomposition also makes it possible for the analyst to group and generalize the SAs into a smaller subset of site-independent GAs, which can then serve as the building blocks for assessments at multiple sites.

7.2.2.1 Development of Generalized Actions (Element GA 2.1)

In this approach, generalized actions are characterized in terms of their performance demands and decoupled from the site-specific MAs of their origin. The nature and relative contribution of specific performance demands to the total task requirement for the GA is called the GA’s performance demand profile. The notion here is to develop a list of GAs that are site-independent and whose performance demand profiles have been established. In the proposed framework, the GAs, combined with site-specific task order and facility layout information, serve as building blocks to represent flood protection and mitigation MAs at any NPP site, and through these effects impact SAs, subtasks, tasks, and MAs. Development of GAs and performance demand profiles would require a procedural method such as expert elicitation, which can be informed by the characterization of the environmental conditions in Chapter 8. Figure 7.2 shows how GAs can be used within this framework.

7.2.3 Characterization of Performance Demands and Performance Measures (Element 3 and GA 3)

In Chapter 5, the research team developed a taxonomy of performance demands to facilitate the assessment of ECs on the performance of MAs. Human performance of any kind relies on human physiological and cognitive capabilities, although the exact nature of the capabilities required varies depending on the action to be performed. For the purposes of this report, the research team characterized the physiological and cognitive abilities that are called upon to meet task performance requirements as performance demands. Based on a review of taxonomies and the research literature, the research team developed a performance demand taxonomy comprising nine major categories[1]. The notion that human performance is affected by ECs via their adverse effects on performance demands is a central concept in this framework. The MAs of interest in this project, and their components (tasks, subtasks, and specific actions) are described well in terms of performance demands.

The panel for "Performance Demand Profiles for Specific Actions (Figure 7.1, Element 3)" in the right-hand column of the framework diagram shows that different SAs have different performance demand profiles. In the GA approach, the "Performance Demand Profiles for Generalized Actions" is followed by applying site-specific information to create site-specific SAs (Figure 7.2, Element GA 3 and GA 3.1).

7.2.4 Characterization of Impacts of Environmental Conditions on Manual Actions (Elements 4, 5 and 6)

The phrase "impact of ECs on MAs" refers to the degradation in performance of MAs caused by ECs. Typical impacts could include the impact of high wind on the ability to work manually with simple equipment, the impact of precipitation on operating vehicles and light or heavy equipment, and the impact of noise on electronic and in-person communication. Typical impacts from secondary ECs could include the impact of waterborne debris on manually moving equipment and the impact of slippery surfaces on walking. As a starting point, the fact that an MA could be affected by an EC should be identified. Some MAs may be performed partially or wholly in sheltered locations where ECs, such as wind or precipitation, are irrelevant. However, these same MAs may be exposed to other ECs such as increased humidity or heat.

ECs associated with specific EC-performance demand intersections can have different degrees of impact on an MA (and by extension on a site-specific SA) depending on the magnitude or severity of the EC and the importance of the performance demand to the performance of the MA. Element 4 intersects identified environmental conditions from Element 1 with performance demands identified in Element 3 or GA 3 in a table to identify those that are and are not pertinent to action being assessed. Chapter 8 is a summary of the reviewed literature, describing how ECs affect performance demands and thereby impact the performance of SAs,

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[1] Performance demands are understanding, decision-making, action – fine motor, action – gross motor, action – other neurophysiological functions, teamwork – reading and writing, teamwork – oral communication and teamwork – crew interaction.

subtasks, tasks, and MAs whose profiles include those performance demands. The impacts table (Element 5) shows that the total impact of ECs on site-specific SAs is determined as a function of the level of the impact of an EC on a performance demand weighted by the contribution of that performance demand to specific SAs or GAs.

As illustrated in the impacts table, the level of impact of EC1 on SA1 would be a weighted sum of the impacts of EC1 on performance demands 1–3. The impacts table also shows that four ECs prevail during performance of SA1 and all affect SA1. Several methods are available to combine the individual effects of several ECs on an action; e.g., additive, multiplicative, and applying a power function. These approaches are described in Chapter 9.

Accounting for all ECs' impacts on the SA then results in the total impact on the SA. Assessing an EC's impact on an MA is accomplished by aggregating the EC's impacts on site-specific SAs that make up the subtasks and/or tasks and ultimately the MA, as shown in Element 6.

8 CHARACTERIZATION OF THE ENVIRONMENTAL CONDITIONS AND THEIR IMPACTS ON PERFORMANCE

This chapter examines the 11 environmental conditions (ECs) that were identified in Chapter 2 that could occur during an external flooding event. These 11 ECs of concern are, with subsection and page number:

The main impacts of these ECs on performance, as identified in the review of the research literature is summarized here and detailed in Volume II. Although the focus of this report is on the ECs that might be associated with external flooding events, these ECs are not limited to such events. Consequently, the information about how the ECs affect performance may be pertinent to the assessment of environmental impacts more broadly. The review of the research literature is an extension and update of that performed by Echeverria et al. (1994).

The chapter begins with a discussion of the method of the review of the research literature, including its critiques and opportunities for improvement. Then each environmental condition is systematically discussed, including research literature, mechanisms of action, broad effects on performance and a summary of examined performance information. More detail on the literature review is documented in Volume II of this report. The chapter ends with a review of temporal and spatial properties of environmental conditions, along with examples that may be relevant in detailed analyses of performance impacts.

8.1 Review of the Research Literature

8.1.1 Method

The research literature was reviewed to update and extend the review reported by Echeverria et al. (1994) hence, the research team built on the literature identified in the previous review. Overall, the present search was designed to find research that addressed the identified ECs, the mechanisms by which these ECs could affect manual actions (MAs), and the nature of those effects. Initially, the search used a list of performance and activity search terms that included both (1) entire tasks and types of MAs (e.g., walking, vehicle operation, construction) and (2) component performance demands. Preliminary review of the results, augmented with consideration of the pertinent NRC human reliability analysis (HRA) methods, led to a refined list of the performance demands as shown in Table 8.1. Alternative terms for these performance demands were also pursued as they were discovered in the literature (e.g., rather than the generic term "vigilance" names of specific tasks[1] often used in the literature).

The set of databases to be searched was intended to capture the discipline areas most relevant to the research problem. These ultimately covered cognitive and experimental psychology, human factors, industrial engineering, industrial hygiene, environmental and occupational health, environmental physiology, and medicine. The chosen databases included Google Scholar, PsychInfo, Web of Science, Science Direct, PubMed, Defense Technical Information Center, and Medline. Professional and government agency websites were also searched for relevant content. These included the National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), U.S. Environmental Protection Agency (EPA), National Weather Service (NWS); National Oceanic and Atmospheric Administration (NOAA), American Conference of Governmental Industrial Hygienists (ACGIH), and Illuminating Engineering Society (IES). The research team performed searches in each of these databases for combinations of the identified ECs for each of the performance demand search terms.

A wide variety of information products were targeted for selection from within these sources. The products included scholarly articles, books, conference proceedings, dissertations, and professional and regulatory organization regulations, guidelines, and fact sheets. Meta-analyses and literature reviews were given special attention. The research team augmented the formal literature search with direct inquiries (by phone or email) to researchers and practitioners currently engaged in the areas of interest. These contacts were asked to identify classical and newly emergent resources that had been found useful in ongoing work and other researchers working in the field who might provide similar recommendations. For the five ECs addressed by Echeverria et al. (1994), special attention was given to research published after their review, because one goal of the project was to determine subsequent advancements in the knowledge about these ECs.

As documents were found, the researchers scanned the title and abstract of each item, liberally reserving those documents that appeared relevant to human performance effects of the given

Table 8.1 Primary performance demands search terms

Detecting and noticing	Attention, memory, vigilance, switching, acuity, perception, threshold perception; sensation, visual recognition
Understanding	Pattern recognition, discrimination, understanding, evaluating, hypothesizing, diagnosing, integrating
Decision-making	Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating options, selecting options
Action	Fine motor skills – discrete, continuous; manual dexterity; gross motor skills – heavy, light; neurophysiology
Teamwork	Reading and writing, oral communication, electronic communication; cooperation, crew interaction, command and control

[1] Throughout this chapter, the term "tasks" most typically reflects its use in the research literature (i.e., an assignment given to or performed by the subjects being studied). The exception is where it is referred to as a "flooding event task" which may be an element of decomposition of MAs into tasks and/or subtasks as described for the framework in Chapter 7. In the research literature, the term task is general in that it can refer to any level of decomposition or composition

EC and discarding those that clearly were not. This process produced an initial set of candidate documents. Members of the research team also introduced candidate documents drawing from their past experience with EC performance effect combinations. The research team members represented the fields of cognitive and experimental psychology, human factors, industrial hygiene, environmental and occupational health and safety, and environmental science. The original Echeverria et al. (1994) review provided both a baseline of knowledge and a database against which to identify major advancements made during the interim period.

Once the relevant documents identified in the search were located, members of the research team read each of them and identified notable EC effects found on the various performance demands. Simultaneously, they identified additional references from citations in the documents that appeared to be relevant. Citations to identified articles also were examined, particularly those pointing to reviews of subsequent integrated reviews and/or meta-analyses (i.e., a forward search process conducted until reaching contemporary research). This process generated a second iteration of the literature search. These articles were read by the research team, who once again noted any references that had not been identified during earlier phases. The process was repeated until the lack of new, relevant documents indicated that the relevant research literature had been effectively identified and reviewed. A list of relevant documents is detailed in Appendix C.

8.1.2 Overview and Critique of the Research Literature

The research literature on environmental effects—as pointed out by Echeverria et al. (1994) and many others earlier and since—reflects a long and diverse history of research into human behavior and performance. The research has come from a wide range of disciplines that offer differing purposes, theoretical frameworks, and approaches. On the one hand, this long history and study diversity provides opportunities for reexamination, validation, and evolution (as well as adding valuable breadth of focus). On the other hand, it has also created a number of challenges for those attempting to aggregate, integrate, and summarize the findings from this research (Gaoua, 2010; Taylor et al., 2016). Key among these challenges are –

- inconsistencies and variability in terminology and categorization of effects
- insufficient specification of and variability in population characteristics, treatments/conditions, and controls
- small study populations not being representative of the workforce
- gaps in examination of the full range of the salient ECs
- shortfalls in examination of the full range of potential effects at equivalent levels of disaggregation
- broad gaps in the examination of co-occurring ECs.

Because of this history, categorization of performance effects, especially cognitive and affective effects, has continued to remain somewhat problematic. In part, this is due to the variability with which researchers have labeled and aggregated results in their studies (i.e., tasks, tests, test panels, and data). Also, in part, it is due to a fundamental difficulty in accurately characterizing the performance demands of a task (i.e., the observed behavior or experimental test). Indeed, different tasks require performance demands that activate different patterns of brain regions (e.g. Qian et al., 2013). Further adding to the categorization challenge is that experience with a task can profoundly alter brain pattern, and hence the appropriate task classification (Bittner, Jr. et al., 1986; Taylor et al., 2016). The relatively recent introduction of improved cognitive models and investigative tools (Parasuraman & Wilson, 2008; Petersen & Posner, 2012; Qian et al., 2013), as discussed below, has made progress in addressing these issues.

The research literature base has grown substantially since the earlier work of Echeverria et al. (1994), but some profound gaps have continued. Echeverria et al. (1994) recognized that simultaneous exposure to more than one EC would typically be encountered at a Nuclear Power Plant (NPP), and they noted a paucity of information about combined effects. The research team found this continues to be largely the case in the research literature. Echeverria et al. provided the example of a combination of noise, heat, and vibration in a turbine building. Similar, if not more aversive, combinations of these ECs might well occur in unsheltered locations during an external flooding event. Clearly, combinations of ECs can occur in both sheltered and unsheltered working environments, but unsheltered environments would typically experience a broader, and perhaps more intense, set of conditions than sheltered environments (e.g., high wind, heavy precipitation, and different qualities of noise). However, aside from a few combinations of ECs (e.g., cold with wind [wind chill], or heat with humidity), the research literature provides little data or theoretical basis for addressing the combined effects of multiple ECs. Consequently, as in Echeverria et al. (1994), this report introduces and discusses ECs individually, even though it is likely that workers could be exposed to multiple ECs during performance of flood protection and mitigation MAs.

The research team also identified a number of secondary ECs (i.e., ECs requiring at least one other enabling EC to occur) that were not addressed in the earlier review. Examples include deep mud or slippery surfaces, which are unlikely conditions without precipitation, ice, or snowpack[2]. Unfortunately, these secondary effects are little addressed in the research literature. The research team anticipates that future research will provide a better understanding of the effects on performance of relevant combinations of ECs and that this research may benefit from the framework and review presented in this report.

8.1.2.1 Knowledge Advances since 1994

8.1.2.1.1 Neuropsychological Research Tools and Methods

Over the two decades since the previous review, the various disciplines have developed increasingly sophisticated theories, techniques, and tools. In addition to advances in test battery development motivated by Echeverria et al. (Echeverria et al., 2002; McCallum et al., 2005), developments have included refinements in biochemical assays, brain imaging, and continuous monitoring equipment. These have enabled a better understanding of the chemical and neurological functioning of the brain and its interaction with the body (Lupien et al., 2007; Parasuraman & Wilson, 2008; Paulus et al., 2009; Petersen & Posner, 2012; Proctor & Vu, 2010). This research has also made considerable progress in clarifying the mechanisms that link the ECs with their cognitive, behavioral, and affective effects and effects on physical performance. As discussed below, considerable progress has been made in clarifying the mechanisms by which discomfort, anxiety, and perceptions of fear—common features of exposure to the ECs that might accompany flooding conditions—affect performance. It has also highlighted the central role attentional demands play in the pattern of performance effects that result.

[2] Slippery surfaces can, however, be caused in the absence of precipitation, ice, or snowpack; e.g., by spilled oil. Snowpack is accumulated snow on the ground or other surfaces.

8.1.2.1.2 Growing Recognition of the Central Role of Effects on Attentional Demand

The greatest knowledge increase since the 1994 review may be a greater appreciation and understanding of the broad role that attentional demand plays in the effects of exposure to a range of ECs (Lupien et al., 2007; Petersen & Posner, 2012; Taylor et al., 2016; Wickens et al., 2016). Echeverria et al. (1994) noted the classical inverted-U hypothesis and the research interest in the performance effects of the attentional demands (e.g., operator workload and many other attentional demand terms) created by changing, distracting, uncomfortable, or dangerous ECs (Lysaght et al., 1989). However, it has taken several decades of research to establish a broader understanding of the mechanism(s) of action and pertinence of attentional demands to performance across a broad range of ECs (Bourne & Yaroush, 2003; Hancock & Desmond, 2001; Lupien et al., 2007). The growing understanding derived from ongoing attentional research is more fully outlined in Volume II of this report.

8.1.2.1.3 Identification of New Retinal Receptors

The identification of fundamentally new sensation receptors is remarkable at the current point in the history of biological science—the physiology of sensory systems has long appeared highly settled. Nevertheless, research on structures previously thought to be well understood has led to new insights into human sensation and perception. The discovery of novel retinal receptors, sensitive to blue/green light, may be the most important advance regarding the impacts of ECs on human visual performance and arousal (Berson, 2003; Brainard et al., 2001; Zele et al., 2011). This subclass of retinal ganglion cells previously was only thought to serve in combining multiple rod and cone information and thereby providing the opponent processing involved in color perception. However, recent study has demonstrated that these receptors provide input affecting both visual sensitivity and the human sleep arousal cycle. These intrinsically photosensitive retinal receptors use blue/green light to provide the brain with the major time giver (zeitgeber) for setting the circadian system. Their existence helps explain the effect light has on arousal and thus performance, which was previously poorly understood.

8.1.2.2 State of the Research across Environmental Conditions

Table 8.2 summarizes the extent to which research supports the assessment of the effects on each of the performance demands for each of the 11 ECs addressed in this report. The rows in the table correspond to the performance demands and the columns correspond to the environmental conditions. In each cell, the status of research is categorized on a scale of 1 to 4, reflecting descending levels of information as noted below the table (i.e., Level 1 denotes information directly applicable to quantitative impacts of an EC and Level 4 denotes an informational gap).

8.1.3 Opportunities for Future Research

Table 8.2 provides a basis for identifying future research opportunities as formally addressed in Volume II. On the one hand, it shows that the review found information with Level 1 quantitative impacts for only 8 out of 99 combinations (environmental conditions by performance demands). This result points toward areas that could be addressed in future research, where Level 1 data most pertinent to NPP flood protection and mitigation response might be developed. On the other hand, only 27 cells are completely void of information useful for either informing a

Table 8.2 Summary of extent to which research supports assessment of effects of environmental conditions on performance demands

Performance Demands	Heat	Cold	Noise	Vibration	Lighting	Humidity	Wind	Precipitation	Standing & moving water	Ice and snowpack	Lightning
Detecting and noticing											
Attention, memory, vigilance, switching, acuity, perception and threshold perception; Sensation and visual recognition	2	2,3	2,3	1,3,4	2,4	2,3,4	4	2,3	3	2	3
Understanding											
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	2,3, 4	4	4	3,4	2,4	4	4	3	3	3	3
Decision-making											
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	3,4	2,3	1,3, 4	3,4	2,4	4	4	3	3	3	3
Action											
Fine motor skills – discrete & motor continuous, manual dexterity	3	2	1,3	1	2	2	4	2	3	2,3	3
Gross motor skills – heavy and light	2	2	4	4	2	3	1	2	1	1,3	3
Other neurophysiological functions	2	3	4	4	2,4	4	4	3	3	4	3
Teamwork											
Reading and writing	4	3	1	2	2,4	4	4	2	3	2	4
In-person and electronic oral communication	2	4	2	3,4	2,4	4	3	4	3	3	3
Cooperation, crew interaction, and command and control	4	4	2,4	3,4	2,4	3	4	4	3	3	4
Research attention →	Extensive	Extensive	Extensive	Considerable, often does not address real world vibrations	Extensive	Mostly addressed as part of heat or cold	Limited literature, mostly on toppling	Limited literature, mostly on vehicle operation	Limited literature, mostly focused on gross motor effects	Very limited lit.	Very limited literature because of danger

Level of Information Categories (1 to 4)

1. *Quantitative information that is directly applicable to determining the quantitative impact of an demand and can be directly used to support the proof-of-concept approach.*
2. *Quantitative information that is of some applicability in determining the degree of impact of an EC on a performance demand (e.g., in some cases, EC severity limits may be available – below a lower limit, there is no discernible impact and above an upper limit, an individual cannot perform an activity at all). Under certain assumptions regarding the variation of impacts with changing severity between the two limits, this information might be used with the proof-of-concept model to provide usable information.*
3. *Qualitative information. General agreement exists that EC affects a performance demand, but measured impacts not reported in research literature, not even for limits. A performance demand may also be affected because a critical cognitive function is primarily impaired. This information might be used to inform a sensitivity analysis using the proof-of-concept model.*
4. *No information (a gap).*

sensitivity analysis (Level 3) or if not, providing sufficient information for basically bounding effects regions (Level 2). Consequently, Table 8.2 represents a basis for identifying research performance to the effects of ECs, research on understudied ECs, and further research on attentional demand. A more comprehensive discussion of future research opportunities may be found in Volume II.

8.2 Characterization of Selected Environmental Conditions

The ECs that are associated with flooding are briefly described in this section. The nature and the units of measurement of each environmental condition are described, followed by a brief overview of the research literature addressing mechanisms of action and performance effects (each with an accompanying graphical overview— the EC effects overview flowcharts). The research team's summary of the ECs' impacts on performance are then presented. In addition, for each environmental condition, a hypothetical flooding scenario is described and the potential impacts on different human capabilities and task requirements of the hypothetical ECs that could exist are characterized. These examples are included to illustrate how the research literature could be applied to estimate the effects of ECs on the performance of specific manual actions. A more complete review of the research literature is provided in Volume II.

8.2.1 Heat

Heat is an EC that has relatively well documented physical and cognitive performance effects. The common environmental unit of measure of heat exposure is the dry (thermometer) bulb air temperature in degrees Celsius (°C) or degrees Fahrenheit (°F). How humans perceive heat exposure, the "apparent" temperature, is a factor of the dry bulb air temperature and the relative humidity, which the NWS reports as the Heat Index (NOAA-NWS, 2014a; Rothfusz, 1990). The Heat Index considers temperature and humidity in shaded areas. The NWS uses the Heat Index to communicate the risk of health effects (e.g., fatigue, cramps, heat exhaustion, or heatstroke) to the public (NOAA-NWS, 2014a). Studies of heat impacts on human performance also consider the combination of temperature, humidity, and wind speed in an assortment of exposure metrics, such as the wet bulb globe temperature (WBGT[1]) or the less inclusive effective temperature (ET[2]) indices (Pilcher et al., 2002). Excessive heat exposure during a flooding event could most likely occur if requisite MAs are conducted in summer months.

8.2.1.1 Research Literature Base

Of the ECs addressed in this report, the effects of heat on human performance have been relatively well studied over the last 50 years. The physiological and related motor performance effects are reasonably well understood. However, the effects of heat on human cognitive performance remain unresolved. Heat aids or hinders performance on specific tasks, under certain conditions and within certain temperature ranges. The nonequivalence of key variables and differences in subject populations across studies are cited as the main reasons for disparate research results (Chase et al., 2005), which challenges clear aggregations of findings across the multitude of heat cognition studies.

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[1] WBGT is a common measure of occupational heat stress. For outdoor situations, it is calculated as WBGT= $0.7t_{nwb}+0.2t_g+0.1t_a$, where t is in °C, t_{nwb} is wet bulb temperature, a measurement of humidity; t_g is globe temperature, a measurement of the amount of solar radiation and t_a is dry bulb, or air temperature.

[2] OSHA guidance (OSHA, 2018) on using the heat index can be found at https://www.osha.gov/SLTC/heatillness/heat_index/pdfs/all_in_one.pdf.

8.2.1.2 Mechanisms of Action

Figure 8.1 presents an overview of heat, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action[3] through which it affects human performance, the effects on human performance, and potential ways in which heat's effects on exposed individuals can be mitigated. The primary mechanisms by which heat affects human performance are as follows:

- *Physiological*. The human body seeks to maintain a constant internal body temperature of approximately 98.6°F (37°C) through homeostatic mechanisms (especially perspiration). As heat and/or exposure time increases, these mechanisms become increasingly overwhelmed, causing internal temperatures to rise and reducing blood flow, and therefore decreased oxygenation to deep tissues, muscles, and the brain.

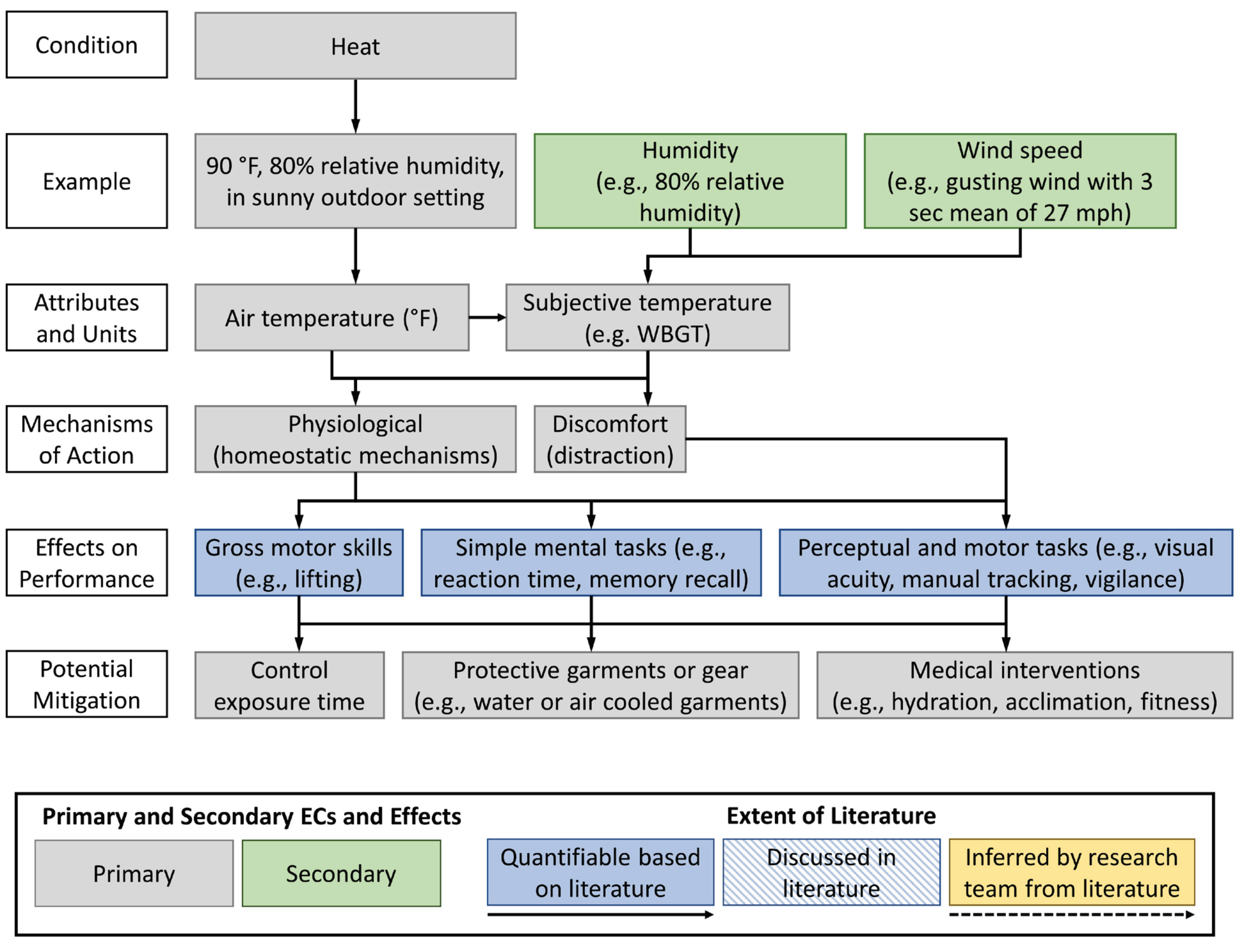


Figure 8.1 Heat effects overview[4]

[3] A mechanism of action is defined as the process through which an EC has its effect on human physiology and/or cognition, and thereby human performance

[4] Only some performance demands are listed here, as others may not be significant for the example condition.

This hypoxia[5] can result in anything from fatigue in mild cases to brain damage in extreme cases (Bjursten et al., 2010; Virués-Ortega et al., 2004). Muscular hypoxia is highly correlated with reductions in strength and physical abilities.

- *Psychological.* Even when heat exposure is not sufficient in amount or duration to affect homeostatic mechanisms, performance decrements still occur. This may be due to anticipation of oncoming heat stress and personal perceptions about the ability to cope with it. This incremental cognitive load, occasionally augmented by perspiration falling into the eyes, may place additional demands on limited cognitive resources, leaving fewer resources available for concurrent tasks, thereby producing the observed cognitive effects (e.g., Hancock & Vasmatzidis, 2003; Lupien et al., 2007; McGrath, 1970; Stress, Cognition, and Human Performance, 2004).

8.2.1.3 Broad Effects on Performance

Research has shown that heat affects human performance in the following ways:

- *Physical strength and endurance.* The literature on heat exposure is very consistent regarding both heat's direct adverse effects on physical strength and endurance, such as repetitive lifting and vigorous exercise, as well as indirect effects, such as accident and injury rates (González-Alonso et al., 1999; Maresh et al., 2014; Mohamed & Srinavin, 2002).
- *Sensation and perception.* There is some evidence that heat exposure, perhaps in part due to perspiration in the eyes, may negatively affect the visual system (e.g., acuity).
- *Cognitive performance.* The literature tends to present opposing patterns of effects for heat on some aspects of cognitive performance, which may be associated with differences in degree and duration of exposure, task context, the specific cognitive tasks used and their difficulty, and training and experience (e.g., Gaoua, 2010; Ramsey, 1995). However, simple cognitive tasks—those requiring only low effort perceptual or motor skills (e.g., simple reaction time, memory recall)—tend to be shown to be less vulnerable to heat stress than more effortful, complex tasks (e.g., a dual task, visual motor tracking, and vigilance [see Volume II, Figure 2.3]).

The relative impacts of heat on individual performance demands for a task performed during a nominal flooding event task[6] are listed in Table 8.3. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the attempted reading of displays during the day, on an exposed platform, at midday, during the summer in a tropical environment following a hurricane. Physical/motor tasks are impacted if heat exposure is sufficient to cause failure of physiological, homeostatic processes. If heat is merely sufficient to produce discomfort, the primary cognitive effects are on complex, central executive tasks. When heat stress is sufficient to change core temperature and begins to affect oxygenation to the brain, cognition begins to fail at multiple loci.

[5] Hypoxia is defined as deficiency in the amount of oxygen reaching the tissues.

[6] "Flooding event task" refers to a task conducting during a flood situation. It is not necessarily a sub-part of an MA or flood causing mechanism, but is used here for a simple task.

Table 8.3 Summary of heat effects on performance and relative impact of enivonmental conditions by performance demands[a]. Illustrative variations based on authors' review of literature for a nominal flooding event task

Performance Demands	Effects of Heat on Performance	Impact of Heat on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Cognitive Performance, Sensation & Perception	Med
Sensation and visual recognition	Sensation & Perception, Cognitive Performance	Med
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Cognitive Performance, Sensation & Perception	Med
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Cognitive Performance, Sensation & Perception	Med
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Physical Strength/Endurance, Sensation & Perception	Med
Gross motor skills – heavy and light	Physical Strength/Endurance, Sensation & Perception,	High
Other neurophysiological functions	Physical Strength/Endurance, Sensation & Perception, Cognitive Performance,	High
Teamwork		
Reading and writing	Cognitive Performance, Sensation & Perception	Med
In-person and electronic oral communication	Cognitive Performance, Sensation & Perception	Low
Cooperation, crew interaction, and command and control	Cognitive Performance, Sensation & Perception	Med

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the attempted reading of displays during the day, on an exposed platform, at midday, during the summer in a tropical environment following a hurricane.

8.2.1.4 Summary of Research Literature Review Results

The detailed literature review of heat is presented in Volume II, Chapter 2. Plots, equations and tables related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
  - Complex, perceptual/motor tasks tend to be affected at lower temperatures than simple, low effort cognitive tasks, but the latter tend to reach their floor more quickly (see Figure 8.2 and in Volume II, Figure 2.3).
- Thresholds, measures for success
  - Heat stress exposure safety limits have recently been established by NIOSH for and non-acclimated (Figure 8.3 below, see Volume II, Figure 2.4 and Figure 2.5) workers for sedentary to heavy work.
  - The U.S. Army Field Manual set allowable work in hot weather operations (Figure 8.2 and in Volume II, Figure 2.3). The Manual indicates **moderate degradation in personnel performance[7] above 85°F and severe degradation above 95°F** (U.S. Army, 1992).
  - Hancock and Vasmatzidis (2003) present a framework for setting heat performance limits for different types of cognitive tasks described by equation $\mathrm{WBGT} = a - 5.435\log_{\mathrm{e}}T$ (8 1), below, and plotted in Figure 8.4 (see Volume II, Figure 2.6) and tabulated in Table 8.4 (Volume II, Table 2.1).
- Qualitative measures
  - Subjective discomfort is reported well before effects on core body temperature begin to occur. The associated distraction/rumination may influence highly effortful tasks.

8.2.1.5 Quantitative Plots, Equations and Tables

This section details plots, equations and tables identified in the summary of research literature review results.

Hancock and Vasmatzidis (2003) developed an equation for attentional involvement based on heat.

$$\mathrm{WBGT} = a - 5.435\log_{\mathrm{e}}T \qquad (8\text{-}1)$$

where *T* is the exposure duration in minutes, *WBGT* is the wet-bulb globe temperature, and *a* represents the intercept values reflecting the attentional involvement required for each task category plotted.

[7] U.S Army Field Manual defines moderate performance impact as normal effectiveness reduced 25-75% and severe impact as normal effective reduce to 0-25%

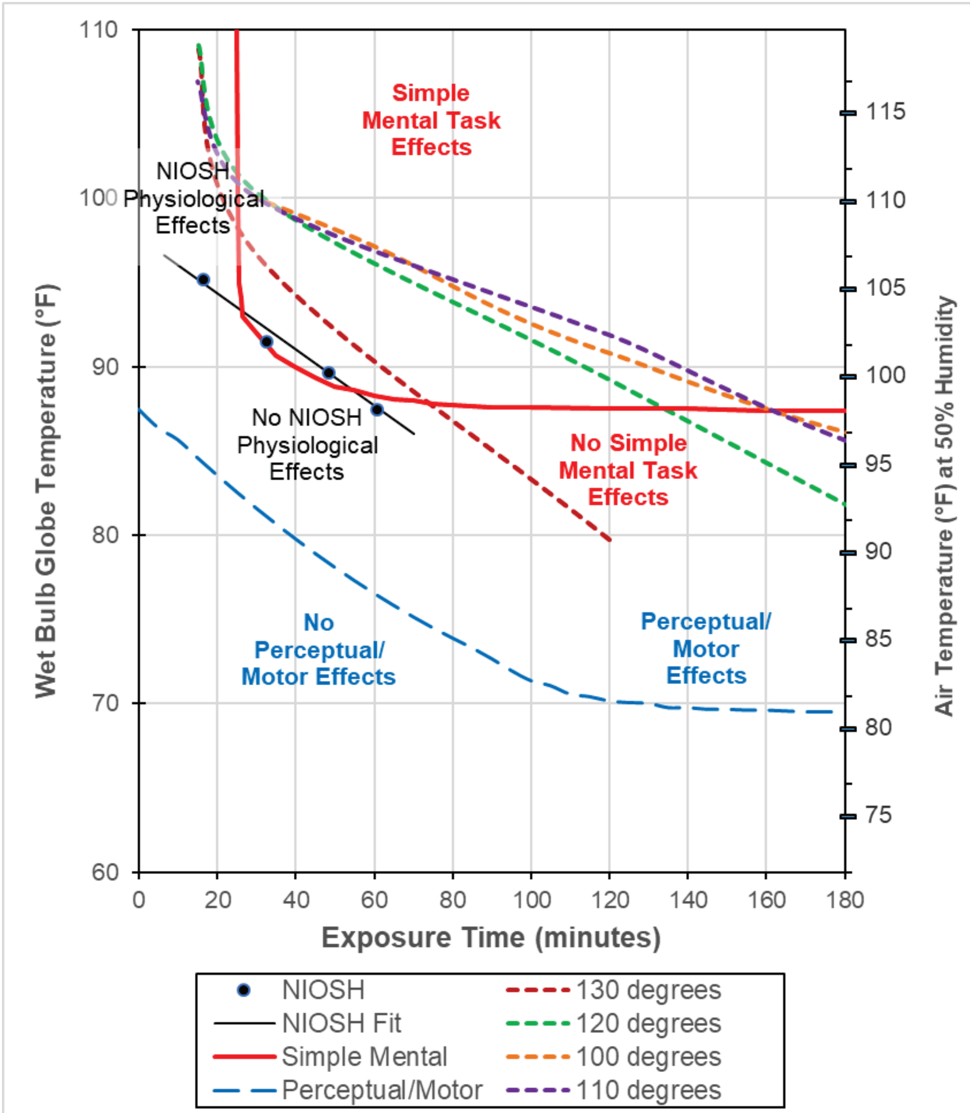


Figure 8.2 WBGT and exposure time effects on physiology and on simple mental and perceptual/motor tasks source. Adapted from Echeverria et al. (1994) and allowable work time for different air temperatures (U.S. Army, 1992 Table L-3).

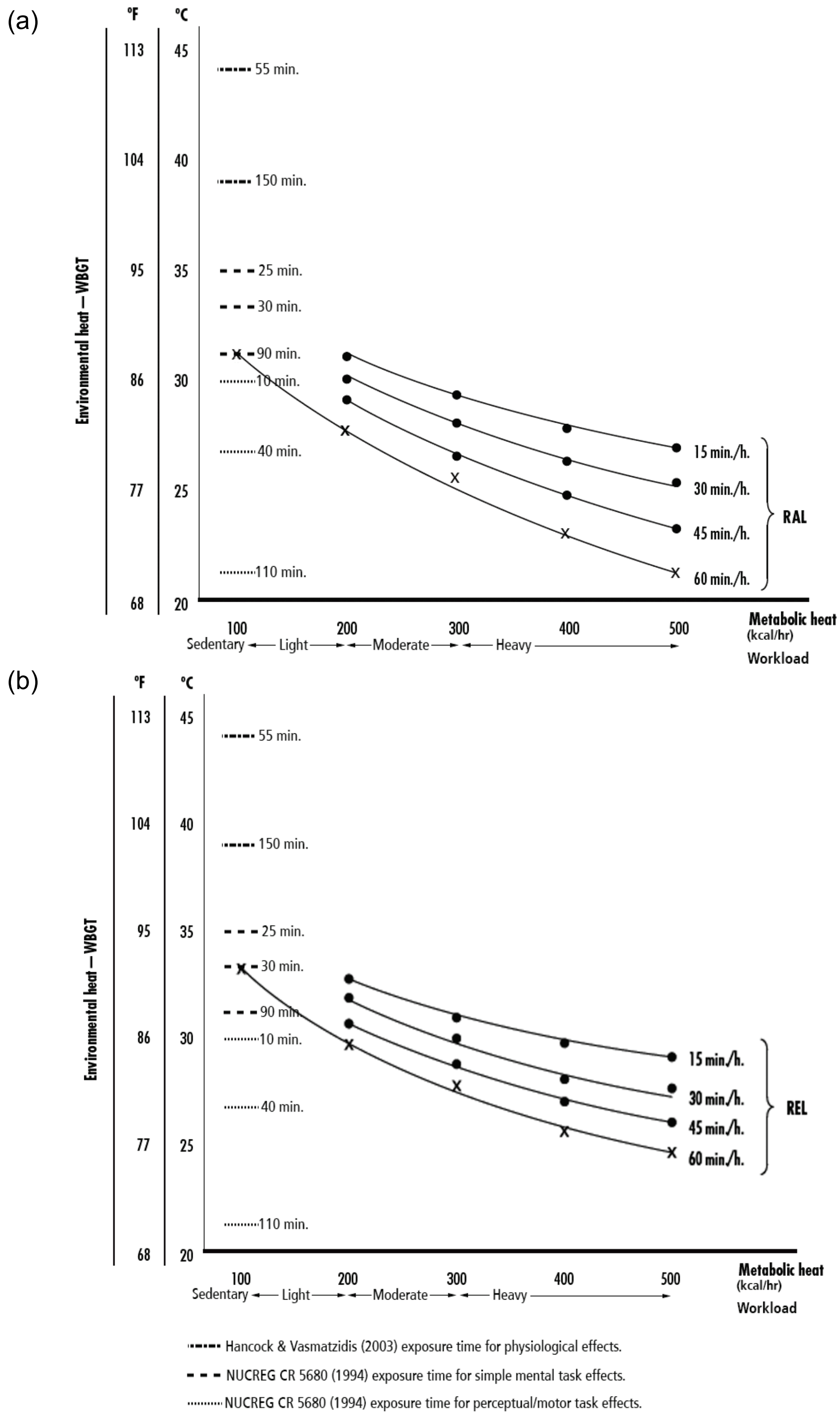


Figure 8.3 Recommended heat stress exposure limits. Panel (a) by recommended alert limits (RALs) and (b) by recommended exposure limits (RELs)[8].

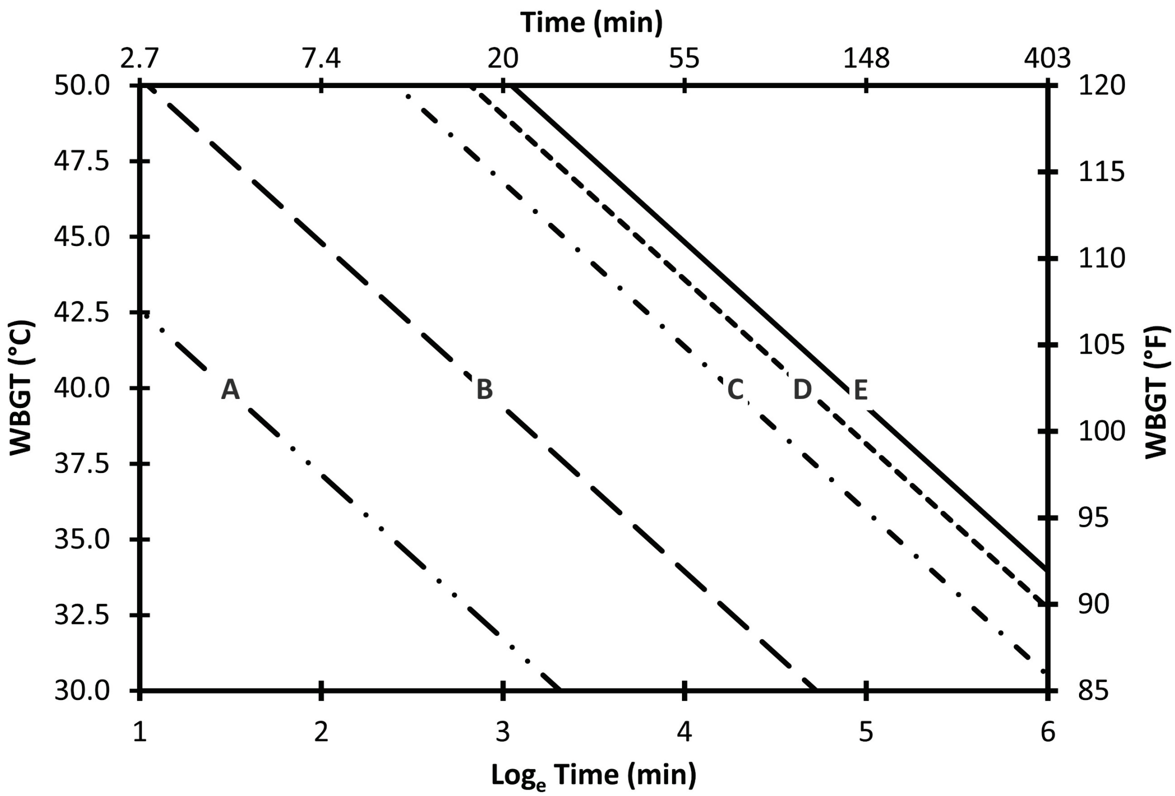


Figure 8.4 WBGT performance limits for various tasks (Hancock & Vasmatzidis, 2003). Lines denote vigilance (A), dual-task (B), tracking (C), and simple mental (D); line E represents the physiological tolerance limit.

Table 8.4 Intercept values for task performance limits in heat

Curve	Task Type	Empirical Intercept for ET* Limits	Tolerance Adjusted Intercept for ET Limits	Empirical Intercept for WBGT^ Limits	Tolerance Adjusted Intercept for WBGT Limits	Dynamic Rise in Deep Body Temperature (°C)
A	Vigilance	42.82	41.00	48.02	45.00	0.055
B	Dual-Task	48.59	47.00	55.68	54.00	0.22
C	Tracking	53.96	53.00	63.11	62.50	0.88
D	Simple Mental	55.81	54.00	65.33	64.00	1.33
E	Physiological Tolerance	57.06	55.00	66.56	65.00	1.67
** ET is effective temperature; ^ WBGT is the wet-bulb globe temperature*						

Source: Hancock & Vasmatzidis, 2003

8.2.2 Cold

Cold has well documented adverse performance effects (NUREG/CR-5680, Echeverria et al., 1994), especially with regard to tasks requiring reasoning, memory, and manual dexterity. As with heat, the most common environmental unit of measure is the dry bulb temperature in °C or °F. Not surprisingly, dry bulb temperature is also the common unit of exposure measurement; however, ET and wind chill indices are other exposure measurements (especially regarding unsheltered workers). These latter measures are particularly relevant as the effects of cold air temperatures on workers are exacerbated by air movement (see Volume II, Chapter 8, Wind) and/or moisture (see Volume II, Chapter 7, Humidity and Chapter 9, Precipitation). Cold temperatures can quickly overwhelm the body's ability to maintain thermal balance and cause hypothermia. However, cold exposure has been shown to adversely affect physical performance well before this point, especially manual dexterity, tactile discrimination, and gross motor strength. There is further evidence of pre-hypothermia cognitive deficits, affecting both short-term retention and working memory. The literature shows mixed results for other cognitive abilities, including reaction time, attention and vigilance tasks, reasoning, and mathematics tasks. Pre-hypothermia cognitive effects are believed to be due in part to discomfort and/or distraction, similar to the effects of heat.

8.2.2.1 Research Literature Base

The literature on cold effects is considerable. The effects of cold have been studied for over a century. Early studies examined the effects of cold on the frequency of industrial accidents rather than on physical and cognitive performance. This focus on the effects of cold in industrial settings was largely because cold was a practical problem due to the difficulty of heating large factories and the ubiquity of outdoor work in winter. Adverse physical effects have been found fairly consistently, whereas adverse cognitive effects show a less straightforward association. This is arguably due in part to the considerable individual differences in mental and physical resources of the research subjects (e.g., young, physically elite research volunteers vs. middle-aged workers).

8.2.2.2 Mechanisms of Action

Figure 8.5 presents an overview of cold, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which cold affects human performance are as follows:

- *Physiological* – loss of thermal balance. When the rate of body heat storage is negative as a result of cold exposure, the adaptive mechanisms of the body cannot maintain a stable internal heat level (i.e., at ~98.6°F), and core temperature will begin to drop (NUREG/CR-5680, Echeverria et al., 1994). This leads to one or more of three bodily responses: (1) heat production; (2) heat conservation; and (3) slowing of the nervous system. Regarding heat production, involuntary shivering increases metabolism, but causes fine motor skills and speech communication to suffer. Regarding heat conservation, to conserve heat, blood vessels in the extremities constrict; whereas; those in the body's core expand. This selectively maintains the heart and other major organs functioning at the expense of extremities, which can negatively affect tactile sensitivity and therefore fine motor skills, and cause muscle weakness. A general slowing of the

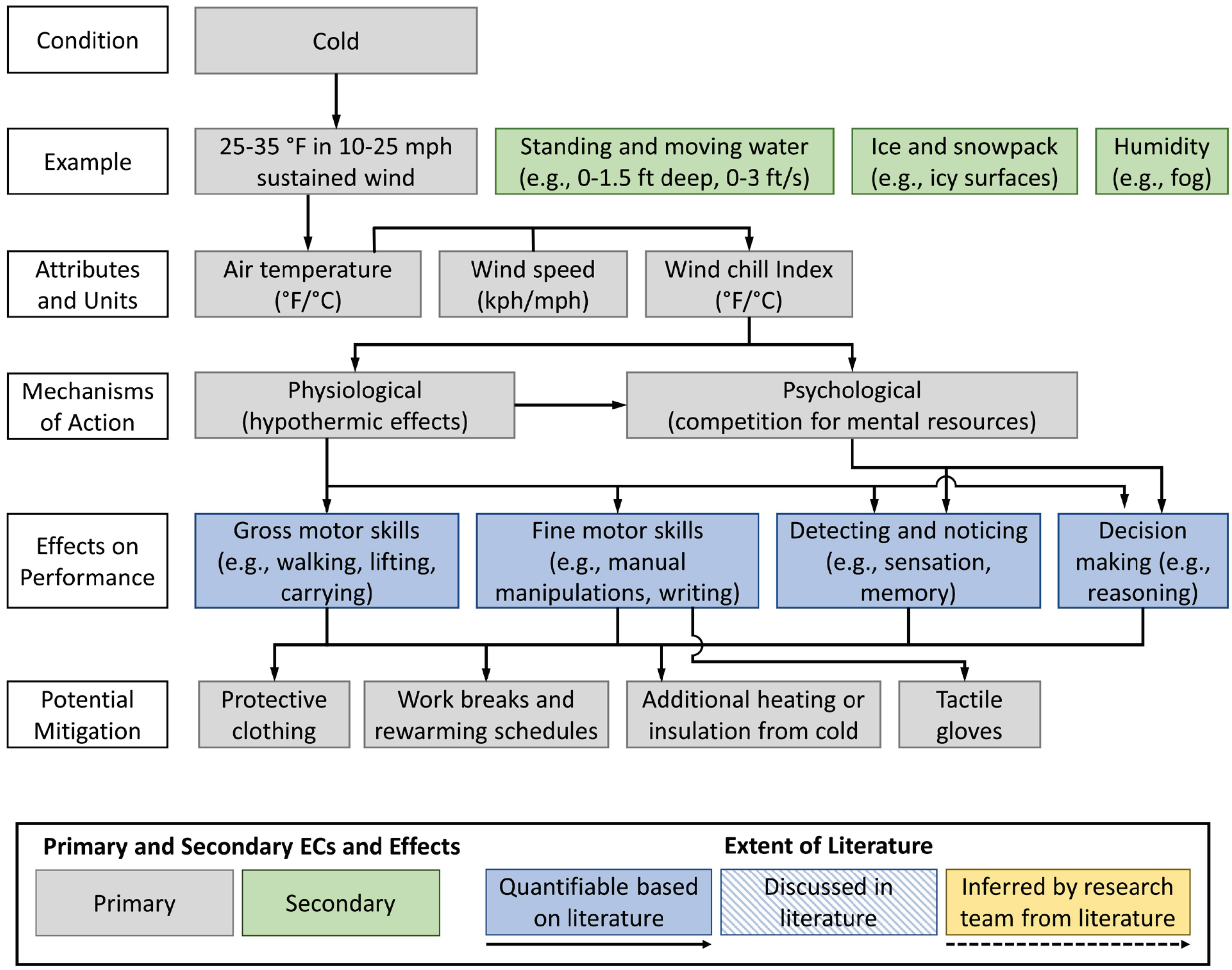


Figure 8.5 Cold effects overview

nervous system to conserve energy would be expected to adversely affect physical reaction time and higher cognition to some degree, accounting for some of the observed effects.

- *Psychological* – distraction/discomfort and arousal. Similar to the effects of heat, the subjective experience of cold may distract the affected individual, drawing limited attentional resources away from physical and cognitive tasks (Teichner, 1958). Experimental findings suggest that as the air temperature drops below ~69°F (~21°C), or the temperature of the hands/fingers drops below ~75°F (~24°C), mild discomfort is experienced. Of note, the probability of performance improvements may typically first briefly increase before precipitously falling, as cold becomes more extreme or persists. Both distraction and arousal theories of cold performance effects fit the patterns shown in the literature, but arousal theory additionally explains the pattern of early performance improvements before collapse (e.g., Poulton & Kerslake, 1965; Provins & Bell, 1970; Wilkinson et al., 1964).

Table 8.5 Summary of cold effects on performance and relative impact of environmental conditions by performance demands[a]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Cold on Performance	Impact of Cold on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Attention, Memory, Tactile Sensitivity	Med[b]
Sensation and visual recognition	Distraction, Attention, and Memory	Med[c]
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Decision-making, Distraction, and Attention	Med-High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Memory, Distraction, and Attention	Med-High[c]
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Manual Dexterity and Tactile Sensitivity	High
Gross motor skills – heavy and light	Muscular Strength	Med
Other neurophysiological functions	Neuro-conduction Speeds	Med
Teamwork		
Reading and writing	Tactile Sensitivity, Distraction-Attention and Memory	Med[c]
In-person and electronic oral communication	Distraction-Attention and Speech interference	Med-High
Cooperation, crew interaction, and command and control	Distraction and Attention	High

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves nighttime flood recovery coordination efforts that require occasional climbing of ladders and reading and adjusting controls as well as speech communications in a partially unsheltered command center, with a low effective temperature of 15 °F that induces occasional shivering
(b) With specific respect to tactile effects.
(c) With specific respect to memory effects.

8.2.2.3 Broad Effects on Performance

Research has shown that cold affects human performance in the following ways:

- *Manual dexterity and tactile sensitivity.* Cold exposure demonstrates relatively consistent performance decrements on the performance of tasks that require manual dexterity, tactile discrimination, and hand strength.
- *Muscular strength.* Local cooling of arms and legs in cold environments can quickly reduce muscle strength and endurance. This is especially important in flooding situations (e.g., where there is increased risk of sinking and drowning, O'Brien et al., 2007).

- *Psychology and cognition.* Certain memory abilities (short-term recall, working memory) show fairly consistent adverse effects of cold, whereas findings are somewhat contradictory for perceptual and vigilance tasks (e.g., Davis et al., 1975; Lockhart et al., 2005; Marrao et al., 2005; Muller et al., 2012; Patil et al., 1995; Shurtleff et al., 1994). For abilities most affected, several studies suggest cognitive deficits may persist for as much as an hour after exposure ceases and physiological measures return to baseline (e.g., Muller et al., 2012).

The relative impacts cold have on individual performance demands for a task performed during a nominal flooding event task are listed in Table 8.5. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves nighttime flood recovery coordination efforts that require occasional climbing of ladders and reading and adjusting controls as well as speech communications in a partially unsheltered command center, with a low effective temperature of 15 °F that induces occasional shivering. Adverse effects on manual dexterity and muscle strength should be expected, and some level of cognitive effects, especially related to tasks requiring memory and possibly attention, may also occur.

8.2.2.4 Summary of Research Literature Review Results

The detailed literature review of cold is presented in Volume II, Chapter 3. Tables related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
    - Formal cold temperature ranges and their quantitative effects have not been established.
- Thresholds, measures for success
    - ACGIH has published **thresholds for work and warmup time per four-hour shift** (Table 8.6; see Volume II, Table 3.4, ACGIH, 2012).
    - The research literature (see Volume II, Chapter 3.5.4) identifies that **temperatures below -23°F** are associated with **quick damage** to exposed flesh (Ramsey, 1975).
    - **Manual dexterity becomes impaired at hand temperatures of ~54–59°F** (~12–15°C, Enander, 1987).
    - **Tactile sensitivity** (due to numbness) becomes **impaired** at somewhat lower **hand temperatures of ~46–50°F** (~8–10°C, Enander, 1987).
    - **Gross manual tasks,** involving interaction with larger objects, begin to **suffer** at lower **air temperatures of ~54°F** (~12°C) and **hand temperatures of ~59°F** (~15°C, Chen et al., 2010; Dusek, 1957).
    - General thresholds for no effect of cold on general discomfort, skin sensitivity, tracking and fine and gross manual tasks are tabulated in Table 8.7 (Volume II, Table 3.2, NUREG/CR-5680, Echeverria et al., 1994).
    - Personnel **experience moderate degradation[9] at less than 32°F and severe degradation at less than -25 °F** according to the U.S. Army Field Manual (U.S. Army, 1992).

The wind chill index, as defined by the equation in

- Table 8.8 (see Volume II, Table 3.1), as a function of measured air temperature with air speed represents what is felt on exposed skin. NOAA-NWS (2017) with has identified **frost bite zones of wind chill index** during which frostbite will occur after a certain **time of exposure**.

[9] U.S Army Field Manual defines moderate performance impact as normal effectiveness reduced 25-75% and severe impact as normal effective reduce to 0-25%

- Qualitative measures
  - Because discomfort is hypothesized to be a component of many environmental effects on cognitive performance, adverse impacts from the EC on worker comfort should be addressed whenever manual actions have a strong cognitive component.

8.2.2.5 Quantitative Tables

This section details tables identified in the summary of research literature review results.

Table 8.6 Threshold limit values for cold exposure

THRESHOLD LIMIT VALUES WORK/WARM-UP SCHEDULE FOR FOUR-HOUR SHIFT*											
Air Temp. Sunny Sky		No Noticeable Wind		5 mph Wind		10 mph Wind		15 mph Wind		20 mph Wind	
°C (approx)	°F (approx)	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks	Max. Work Period	No. of Breaks
-26° to -28°	-15° to -19°	(Norm breaks) 1		(Norm breaks) 1		75 min.	2	55 min.	3	40 min.	4
-29° to -31°	-20° to -24°	(Norm breaks) 1		75 min.	2	55 min.	3	40 min.	4	30 min.	5
-32° to -34°	-25° to -29°	75 min.	2	55 min.	3	40 min.	4	30 min.	5	Non-emergency work should cease	
-35° to -37°	-30° to -34°	55 min.	3	40 min.	4	30 min.	5	Non-emergency work should cease			
-38° to -39°	-35° to -39°	40 min.	4	30 min.	5	Non-emergency work should cease					
-40° to -42°	-40° to -44°	30 min.	5	Non-emergency work should cease							
-43° to below	45° to below	Non-emergency work should cease									

Source: American Conference of Governmental and Industrial Hygienists (ACGIH, 2012)

Table 8.7 Temperatures above which no cold effects occur

Effect of Exposure to Cold		Air Temperature (°F)	Hand Skin Temperature (°F)
General Discomfort		69	75
Effects of Cold on the Hands			
	Skin Sensitivity		75
	Numbness	54	68
	Pain		61
	Finger Discrimination		37
	Grip Strength	14	
Task Performance			
	Fine Manual Tasks	64	55
	Tracking	55	
	Gross Manual Tasks	54	59

Source: NUREG/CR-5680, Echeverria et al., 1994: Table 5.2

Table 8.8 Time to frost bite based on wind and cold temperature

Temperature (°F)

Wind (mph) / Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	29	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	28	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	27	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	26	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-19	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-34	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	26	19	12	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes; 10 minutes; 5 minutes

$$\text{Wind Chill (°F)} = 35.74 + 0.621T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, *T* = Air Temperature (°F) *V* = Wind Speed (mph)

Source: NOAA-NWS, 2017(effective 11/01/01)

8.2.3 Noise

Noise is defined as unwanted sound. Echeverria et al. (1994) described noise as the most common EC encountered in an industrial setting. With considerable expansions based on more recent research, the following characterization of noise effects is built upon the description in their earlier work. Noise has a wide range of sources and characteristics or qualities (e.g., frequency, intensity, continuity, intermittence, transience, attenuation, and direction). Across these, noise can affect performance in multiple ways including interfering with communication, increasing annoyance or anxiety, causing a temporary shift in hearing ability, and posing a safety hazard to personnel. Different types of noise, such as familiar vs. unfamiliar and continuous vs. impulse, affect performance differently. Performance is also sensitive to both the duration of noise exposure and task complexity. The basic measures of sound are frequency in hertz (Hz) and intensity in decibels (dB). Humans perceive frequency and intensity in the range of hearing as pitch and loudness; infra-sound outside the auditory range may be felt, though not heard. Because human hearing is not equally sensitive to all frequencies, loudness is perceived differently at different frequencies, and the highest sensitivity (perceived loudest sound) is at around 3,000 Hz (Nave, 2016). This is accounted for by weighting the dB scale; the A-weighted scale, dB(A), is the most commonly used because it approximates the ear’s frequency response for sound below 55 dB and is the most sensitive (NUREG/CR-5680, Echeverria et al., 1994).

8.2.3.1 Research Literature Base

The effects of sound and associated noise on performance has been long studied and better quantified than most of the ECs addressed in this report. This is not surprising because it has been long recognized as important in industrial and military settings. Much of the historic literature deals with noise interference with auditory detection and perception over the range from simple signals to speech communication. Substantial bodies of more recent research document diverse impacts both on cognitive processes, especially from background speech noise, and gross motor tasks, especially from low frequency noise (2-200 Hz) that affects the semicircular canals of the inner ear (and thereby balance). Stress and arousal are increasingly seen to have substantial effects on both well-being and performance (e.g., cognition and gross motor skills, Botteldooren et al., 2008; Schlittmeier et al., 2015).

8.2.3.2 Mechanisms of Action

Figure 8.6 presents an overview of noise, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. These topics are comprehensively addressed in Volume II, Chapter 4.
The primary mechanisms by which noise affects human performance are as follows:

- *Interference with detection and perception of auditory signals*. Noise can directly interfere with the detection and perception of auditory signals both from masking when coincidental as well as during recovery from sound exposures.
- *Disruptions of verbal information processing.* Noise, particularly from background speech, interferes with the phonological loop segment of working memory that deals with acoustic information (e.g., speech and interpretation of written words, Baddeley & Hitch, 1974). This disrupts the performance of tasks that involve processing verbal information (e.g., reading and interpreting text, as well as those involving remembering, understanding, and manipulating auditory information).

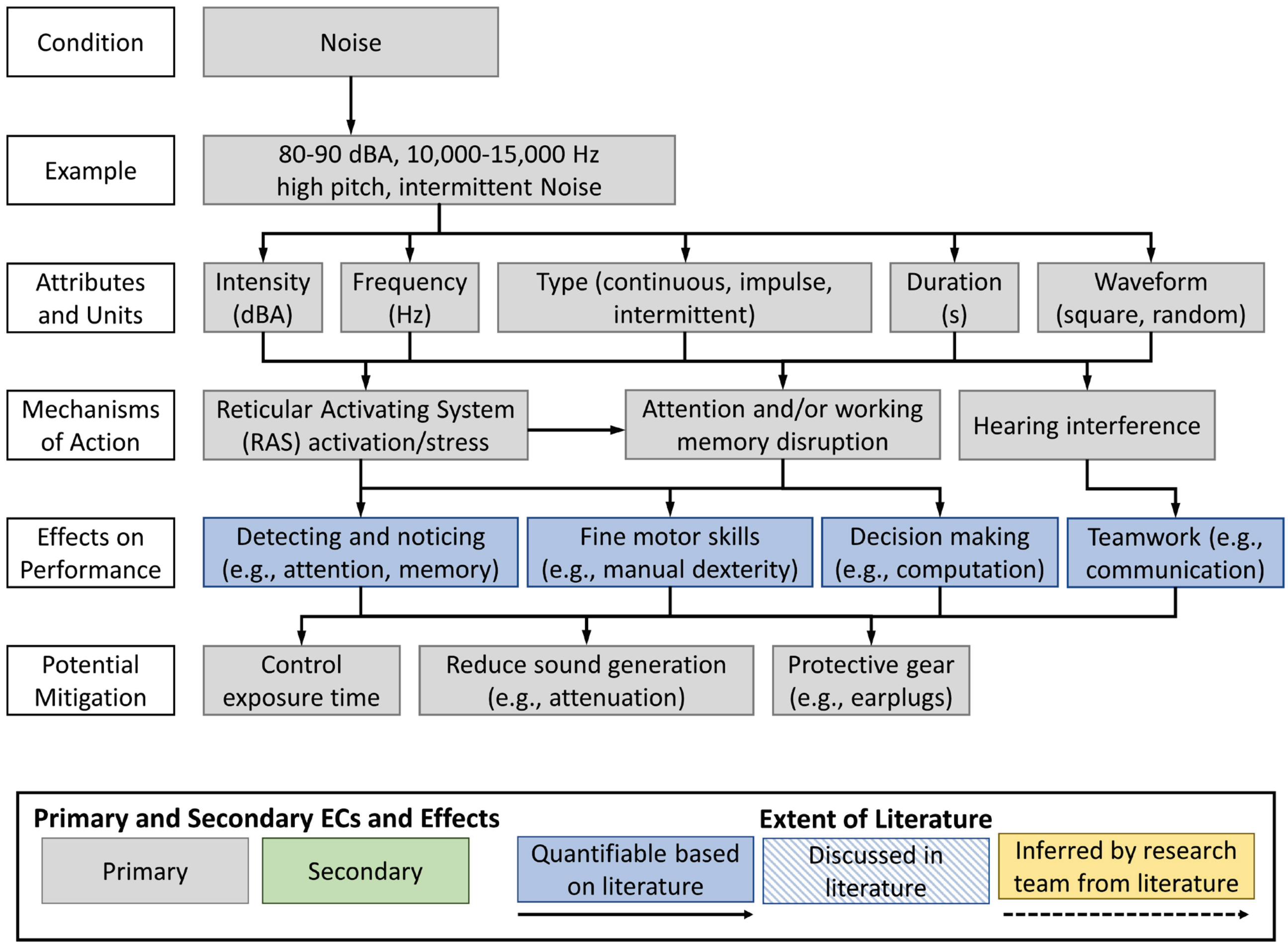


Figure 8.6 Noise effects overview

- *Disruptions of motor performance.* Noise, particularly low frequency noise (2-200 Hz) but also sustained high intensity noise (>95 dB(A)), can adversely affect balance, standing steadiness, walking carrying capability, as well as performance of manual handling tasks such as walking, lifting, pushing, etc. (EnHealth Council, 2004). Stress and arousal, which can be induced by high levels of noise, have also been found to adversely affect coordination during gross motor activities.
- *Stress, arousal, and discomfort.* Studies have shown that noise increases stress, arousal, and discomfort, which can directly impair the ability to focus on a task at hand (whatever its nature but most adversely, if the task is complex and/or cognitive and requires sustained attention, (Botteldooren et al., 2008; Schlittmeier et al., 2015)). Adverse effects are more pronounced when the worker does not control the start and stop of the noise (e.g., Wohlwill et al., 1976).

8.2.3.3 Broad Effects on Performance

Research has shown that noise affects human performance in the following ways:

- *Auditory sensing and understanding*. Noise can adversely affect the range of auditory sensing and understanding, from simple signal detection to speech communication, primarily by masking the communicated information (i.e., affecting the receiving pathway). Speech communication is most affected by multiple speaker background noise, arguably reflecting an attentional disruption (e.g., Jones, 1990; Salamé & Baddeley, 1982). Aural communication disruptions adversely affect higher order cognitive processes and motor components that are contingent on the affected information.
- *Fine motor skills.* Negative effects of noise on the performance of several practical fine motor control and manual dexterity tasks have been recently demonstrated (Nassiri et al., 2013). The fact that fine motor skills are most sensitive to particularly annoying aperiodic and high frequency noise appears to reflect the adverse effects of attentional disruptions.
- *Attention.* Noise, via its level of annoyance, has broad adverse effects on cognitive tasks involving attention and memory, as well as more complex tasks involving verbal information processing (e.g., verbal communication and verbal and reading comprehension). It has also been shown to be disruptive of psychomotor integration tasks, but rarely simple non-aural detection tasks (e.g. visual). Annoyance and attentional disruptions tend to be greatest with ongoing noise that is unpredictable in period, frequency, and intensity (Casali & Robinson, 1999; Szalma & Hancock, 2011).
- *Vigilance.* Response speed and errors on this largely attentional task both tend to increase with noise stress, with their relative increases depending on individual shifts in strategy and ability to withhold routinized motor responses. Reduced adaptation to modifications in target probabilities can also occur (Dornic & Fernaeus, 1981; Smith, 1985). These vigilance performance disruptions appear to reflect effects on attention, because they are similarly vulnerable to ongoing noise that is unpredictable in period, frequency, and intensity (e.g., Smith, 1988; Smith & Miles, 1987).
- *Teamwork.* Noise may directly disrupt oral communications, and consequently associated aspects of crew integration and coordination. Noise, via its associated stress and attentional resource reductions, may also further adversely affect oral communications and crew integration and coordination.

The relative impacts of these broad noise effects on individual performance demands may be assigned for a nominal flooding event task, as illustrated in Table 8.9. This nominal flooding event task assumes that two workers have been sent outside to ascertain, report, and coordinate actions to be taken after an electronic equipment alert signals from portable equipment on an external platform. Near the platform there is also an auditory alert, but it is being masked by the worker's ear protection equipment as well as wind and increasingly loud equipment noise (perhaps reflecting an ongoing major failure). Communication is required to coordinate the actions of the workers after the nature of event is understood and options are weighed. In this example, under detecting and noticing, it is assumed that workers wearing noise protectors with internal earphones and using a noise-canceling microphone would experience muting of external auditory signals, making them difficult to detect. Communication via electronic devices could be adversely affected at a medium level (Med), in part because of wind noise, but also because the equipment failure noise the workers would need to detect would be blocked by the noise-canceling microphone in their communication equipment. This would typically affect subsequent communications-dependent performance demands at a medium level. In contrast, gross motor skills would be little affected (Low). If the impact on

Table 8.9 Summary of illustrative noise effect on performance and relative impact of environmental conditions by performance demands[(a)]. Illustrative variations based on authors' review of literature for a nominal flooding event task where the personnel are wearing noise protection.

Performance Demands	Effects of Noise on Performance	Impact of Noise on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Attention, Auditory	High
Sensation and aural recognition	Auditory Acuity	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Attention, Speech Recognition, Cognition	Med
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Attention, Cognition	Med
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Manual Tracking[(b)] and Fine Motor Tasks	Med
Gross motor skills – heavy and light	---	Low
Other neurophysiological functions	Neurochemical	Med
Teamwork		
Reading and writing	Visual Acuity, Cognition	Med
In-person and electronic oral communication	Cognition	Med
Cooperation, crew interaction, and command and control	Attention Cognition	Med-High

(a) The nominal flooding event task assumes that two workers have been sent outside to ascertain report and coordinate actions to be taken following an electronic equipment alert signal from portable equipment on an external platform. Near the platform there is also an auditory alert, but it is being masked by the ear protection as well as wind and increasingly loud equipment noise (perhaps reflecting an ongoing major failure). Communication is required to coordinate the actions of the workers after the nature of event is understood and options are weighed.
(b) Manual tracking is setting features manually and tracking them by hand rather than relying on auto-tracking, such as by using a joystick

electronic communication was greater, a realistic possibility (High) as the noise cancelation microphone becomes unavailable, then other medium impacts would typically become high, with the exceptions of fine motor and gross motor skills, which would remain respectively medium and low because of the noise-canceling ear protection equipment.

8.2.3.4 Summary of Research Literature Review Results

The detailed literature review of noise is presented in Volume II, Chapter 4. Plots and tables related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
    - Noise has been shown to adversely impact several performance demands, including aural communication, which is particularly affected by background speech noise; attention; cognition, especially that involving verbal information processing, memory and attention, and psychomotor integration; vigilance; and fine motor skills. As discussed in more detail in Volume II, Chapter 4, these effects are mediated by various attributes of the noise (e.g., aperiodic vs continuous, intensity, and degree under "worker's" control). Effects were estimated by Hancock et al. (2005) in terms of IMPRINT Taxons (Table 8.10; see Volume II, Table 4.1)
    - Noise, very **low frequency noise (2-200 Hz**) but also **sustained high intensity noise (>95 dB (A)**), can **adversely affect balance**, which affects standing steadiness and walking carrying ability (EnHealth Council, 2004; Schultz et al., 1976). Stress and arousal, which can be induced by high levels of noise, adversely affect coordination during gross motor activities (Figure 8.7; Volume II, Figure 4.6).
- Thresholds and measures for success
    - Recommended exposure limits have been delineated with some variations across agencies. **85 dB (A)** is the most conservative limit **for 8 hours of exposure** across agencies (Table 8.11; see Volume II, Table 4.2 (ACGIH, 2006)).
    - **Allowable noise level** pressure **between 90 dB (A) and 115 dB (A)** also have been delineated (Table 8.12; see Volume II, Table 4.3, OSHA(29 CFR 1910.95, 1996)).
    - **Exposure to impulsive or impact noise** has also **been limited to 140 dB** peak sound pressure. (Volume II, 4.5.8, Para 1).
- Qualitative measures
    - The percentage of respondents highly annoyed by an outdoor noise level has been broadly identified, with 50% indicating high annoyance at ~76+4 dB and ~5+5% at 50 dB (A) (see Volume II, Figure 4.6). High annoyance would adversely affect detecting and noticing; understanding; decision-making; fine motor skills; other neurophysiological functions; and teamwork.

8.2.3.5 Quantitative Plot and Tables

This section details a plot and tables identified in the summary of research literature review results.

Table 8.10 Proposed taxon impacts of noise for the IMPRINT Model

IMPRINT Taxon	Accuracy	Speed
Perception – Visual Recognition/Discrimination	-0.4%[(a)]	2.4[(a)]
Numerical Analysis	-31.8%	-16.8%
Fine Motor Discrete	-9.9%[(a)]	-33.6%
Fine Motor Continuous	-19.9%[(a)]	-13.1%[(a)]
Communication – Reading & Writing	-23.7%	1.4%[(a)]
Communication – Oral	-29.0%[(a)]	ID[(b)]

Positive percentages reflect facilitation of the task, negative percentages reflect decrements.
(a) The confidence intervals for these effects contain zero, thus noise may have very small or zero statistical effect on these tasks. (b) Indeterminate

Source: based on Hancock et al., 2005

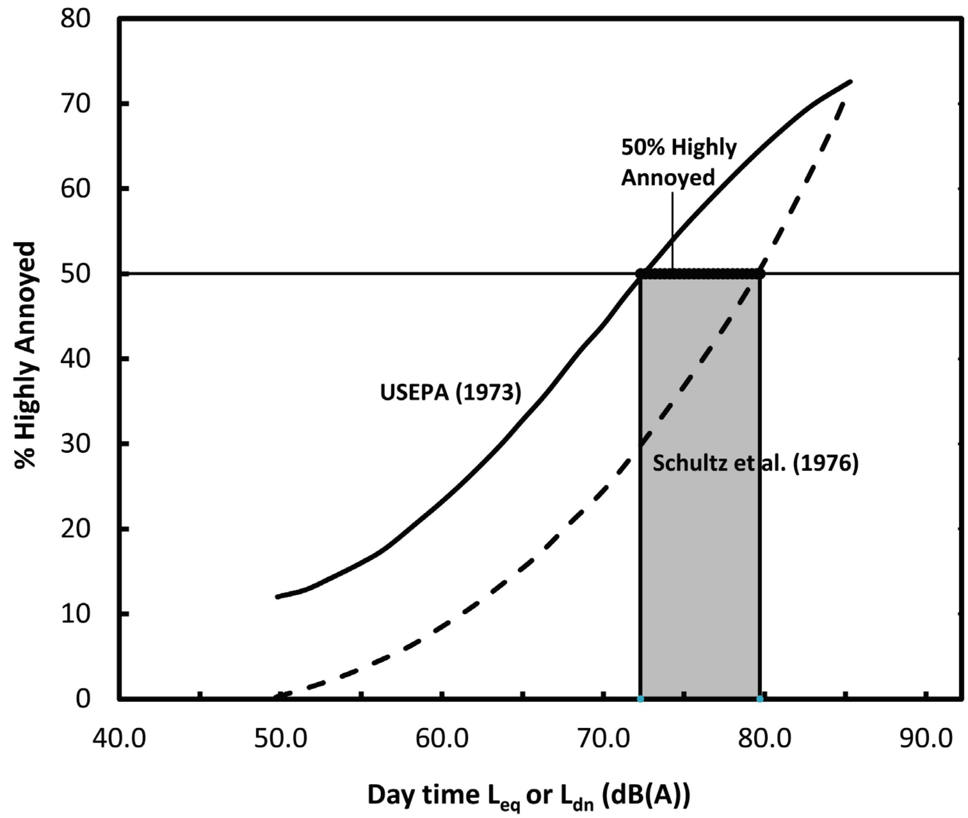


Figure 8.7 Percentage of respondents highly annoyed by outdoor noise level. Curves fitted to results from several social surveys in different countries.

Table 8.11 Limits for noise over an 8-hour period by various regulating agencies

Agency	Permissible Exposure Limits
OSHA	90 dB(A) (TWA)[a]
NIOSH	85 dB(A) (TWA)[b]
ACGIH	85 dB(A) (TWA)[c]

(a) 29 CFR 1910 (1996) *OSHA General Industry Regulations, Subpart G Occupational Health & Environmental Control, §1910.95 Occupational noise exposure*
(b) Rosenstock (1998)*. Criteria for a recommended standard: Occupational noise exposure. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.*
(c) American Conference of Governmental and Industrial Hygienists (2006)*.*

Table 8.12 Allowable noise level from OSHA and NIOSH/ACGIH standards

OSHA Level dB(A)	Allowable Duration	NIOSH/ ACGIH Level dB(A)
90	8 h	*85*
95	4 h	88
100	2 h	91
105	1 h	94
110	30 min	97
115	15 min	100

Sources: OSHA: 29 CFR 1910.95, 1996; ACGIH, 2006

8.2.4 Vibration

Vibration, figure defined as an oscillating motion characterized by frequency and acceleration, is another EC described in detail by Echeverria et al. (1994) that was identified as being commonly encountered in an industrial setting. Vibration affects performance by causing discomfort, impaired ability to read text and numbers, and impaired manual tracking. Sustained vibration-blurred vision can lead to nausea and other symptoms of perceptual conflicts (e.g., Bittner & Guignard, 1985a, 1985b; Helmkamp et al., 1984). The following characterization of vibration builds upon its description by Echeverria et al. (1994). Vibration frequency is measured in hertz, while the acceleration (representing the force or intensity) of vibration is measured in meters per second squared (m/s^2) or expressed relative to the acceleration due to gravity (g), which is 9.8 m/s^2. Because Echeverria et al. (1994) focused on ECs inside the plant, they did not address potential environmental sources of vibration (e.g., riverine floodwater or storm surge/tides).

8.2.4.1 Research Literature Base

The effects of vibration have been more studied and better quantified than most of the ECs addressed in this report, in part because vibration is an important factor in many industrial settings. The largest body of research relevant to flooding events is that conducted on whole body vibration. Cognitive impacts from vibration are difficult to separate from impacts on vision and those resulting from the noise that often accompanies vibration. Chronic exposure, increased frequency and acceleration, and proximity to the resonant frequency of the eye are all linked in the research literature to greater adverse performance impacts.

8.2.4.2 Mechanisms of Action

Figure 8.8 presents an overview of vibration, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which vibration affects human performance are as follows:

- *Disruption of perception*. Vibration affects visual and manual tracking tasks due to the relative movement of the viewed object and the retina. Blurred vision and poor visual performance ensue.
- *Mechanical disruption of motor control*. Vibration mechanically disrupts the control needed in tracking tasks or tasks requiring fine motor control.

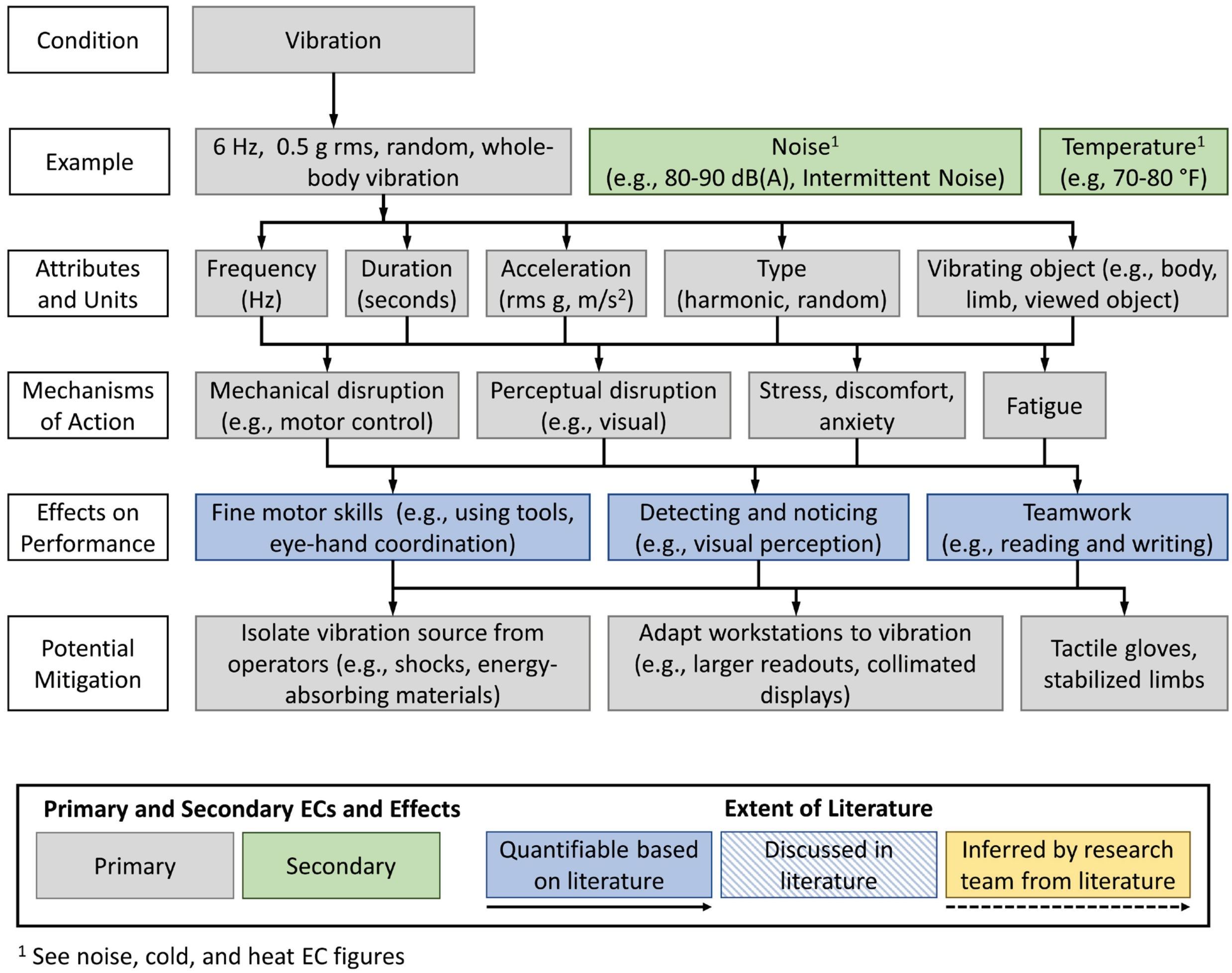


Figure 8.8 Vibration effects overview

- *Stress, arousal, and discomfort.* Studies have shown increases in stress, arousal, and discomfort with vibration frequency and acceleration as well as with chronic exposure to vibration (e.g., Helmkamp et al., 1984; Ljungberg et al., 2004).

8.2.4.3 Broad Effects on Performance

Research has shown that vibration affects human performance in the following ways:

- *Visual acuity:* Visual acuity is dependent on frequency and acceleration. Curves exist that relate error-free reading to these parameters.
- *Manual tracking and fine motor tasks*. Vibration adversely affects hand-eye coordination, which adversely affects fine motor tasks and manual tracking behaviors (Lawton & Miller, 2006; Woldstad et al., 1982).
- *Attention.* Errors increase with discomfort caused by vibration and attention sensitive task performance declines (e.g., Griffin, 2012; Ljungberg et al., 2004); the severity of these effects corresponds with the discomfort thresholds established by the International Standards Organization (ISO).

- *Cognition.* Studies have shown adverse impacts on many measures of cognition, but their effect is difficult to separate from the visual or noise effects (e.g., as cognition may be impaired, or may be impossible, when it is difficult to adequately see or hear relevant cues). Measures affected included learning rates, timesharing, memorization, and inductive reasoning (Schipani et al., 1998; Sherwood & Griffin, 1992).
- *Teamwork*. Reading and writing may be disrupted due to impairment of visual acuity. Also, stress and attentional costs have been shown to affect the quantity and quality of communication and associated coordination.

The relative impacts of these broad vibration effects on individual performance demands may be assigned for a nominal flooding event task, as illustrated in Table 8.13. This nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the attempted reading of displays on an exposed platform that is vibrating because of both the operation of a nearby

Table 8.13 Summary of vibration effects on performance and relative impact of environmental conditions by performance demands[(a)]. Illustrative valuations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Vibration on Performance	Impact of Vibration on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Attention, Visual Acuity	Med/High[(b)]
Sensation and visual recognition	Visual and Tactile Acuity	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Attention, Visual Acuity, Cognition	Med
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Attention, Cognition	Med
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Manual Tracking and Fine Motor Tasks	Med
Gross motor skills – heavy and light	---	Low
Other neurophysiological functions	---	Med
Teamwork		
Reading and writing	Visual Acuity, Cognition	High
In-person and electronic oral communication	Attention Cognition	Med
Cooperation, crew interaction, and command and control	Attention, Cognition	Med

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involved the attempted reading of displays on an exposed platform that is vibrating both because of a nearby portable emergency pump operation and buffeting floodwaters.
(b) If the impacts of vibration were greater -- a realistic possibility -- then adverse effects on Detecting and Noticing could appropriately be scored as "High."

portable emergency pump (that may be responding to floodwaters) and buffeting due to floodwaters. In this illustration under detecting and noticing, it is concluded that the effect on visual acuity would be High (e.g., based on Figure 5.4 in Volume II), but there are only modest effects on attention and memory because their corresponding salient perceptual cues may not be severely affected even though visual acuity is severely affected. If the impacts of vibration were greater -- a realistic possibility -- then adverse effects on the performance demands dependent on the lower level cues (i.e., attention, memory, vigilance, switching, acuity, perception and threshold perception) could appropriately be scored as “High.”

8.2.4.4 Summary of Research Literature Review Results

A detailed review of the research literature on vibration is presented in Volume II, Chapter 5. Plots related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
    - Discomfort boundaries for increasing vibration exposure times were developed by ISO (Figure 8.9; see Volume II, Figure 5.3 (NUREG/CR-5680, Echeverria et al., 1994)).
- Thresholds, measures for success
    - **Vision is completely disrupted** at or near **30Hz** (resonant frequency of the eye, Lawton & Miller, 2006).
    - Text **reading errors due to vibration** (Figure 8.10; see Volume II, Figure 5.4 (NUREG/CR-5680, Echeverria et al., 1994)).
    - **Baseline tracking** is unaffected at or below the 0% line (Figure 8.11; see Volume II, Figure 5.5).
- Qualitative measures
    - Sustained vibration of any frequency can lead to sensation of nausea/motion sickness (apparently due to visual blurring and inner ear effects (Helmkamp et al., 1984).

8.2.4.5 Quantitative Plots

This section details plots identified in the summary of research literature review results.

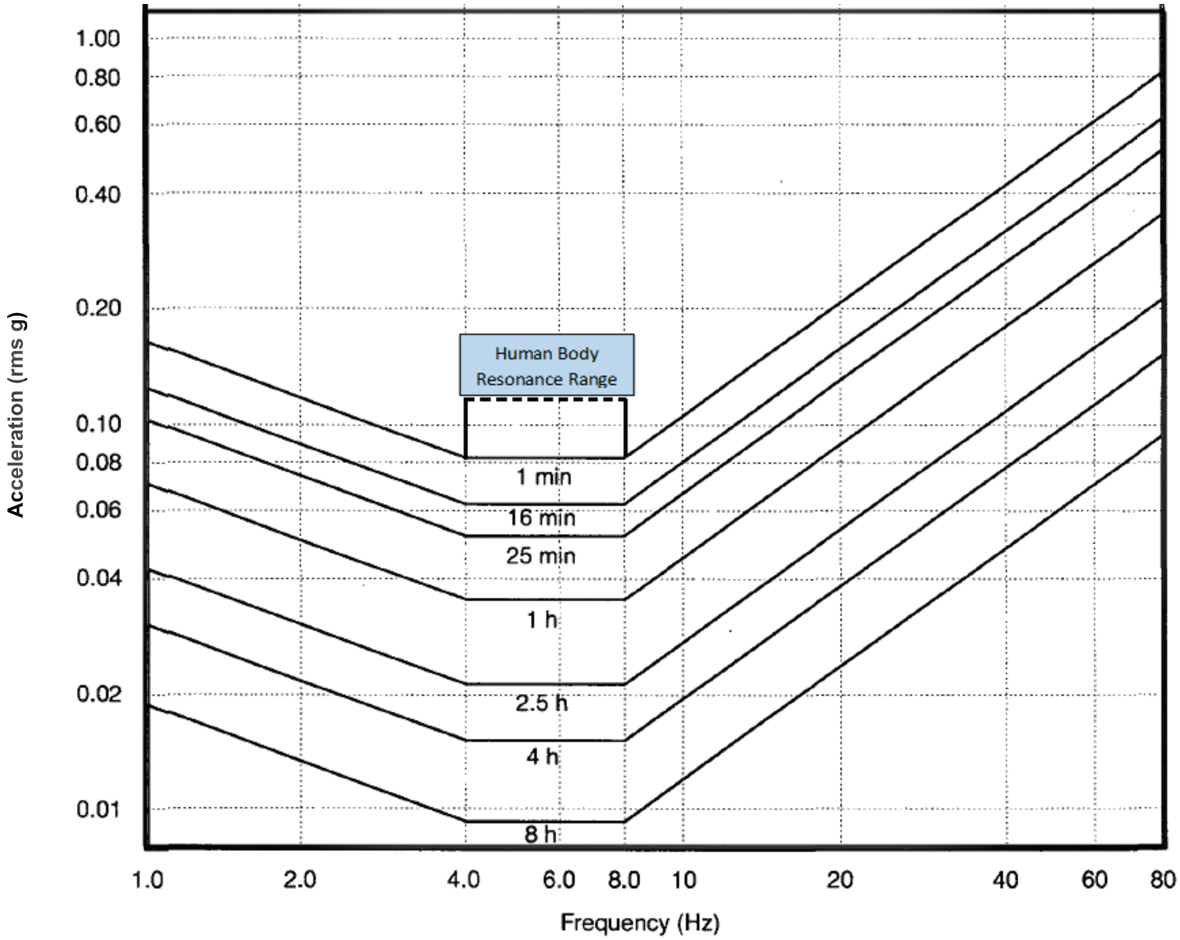


Figure 8.9 Discomfort boundaries by exposure time and observed vibration characteristics (ISO in NUREG/CR-5680, Echeverria et al., 1994)

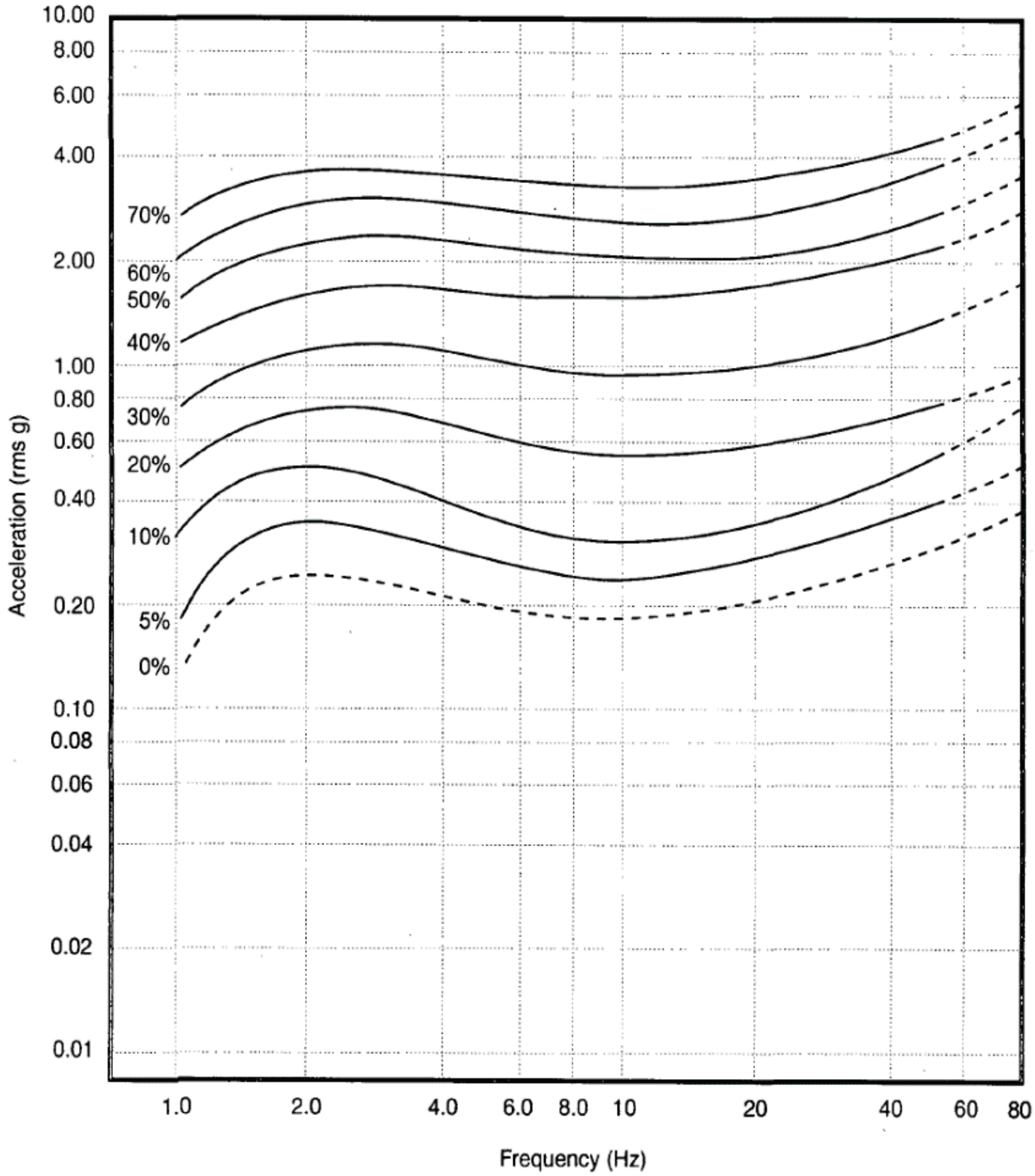


Figure 8.10 Effects on visual acuity by observed vibration characteristics (ISO in NUREG/CR-5680, Echeverria et al., 1994)

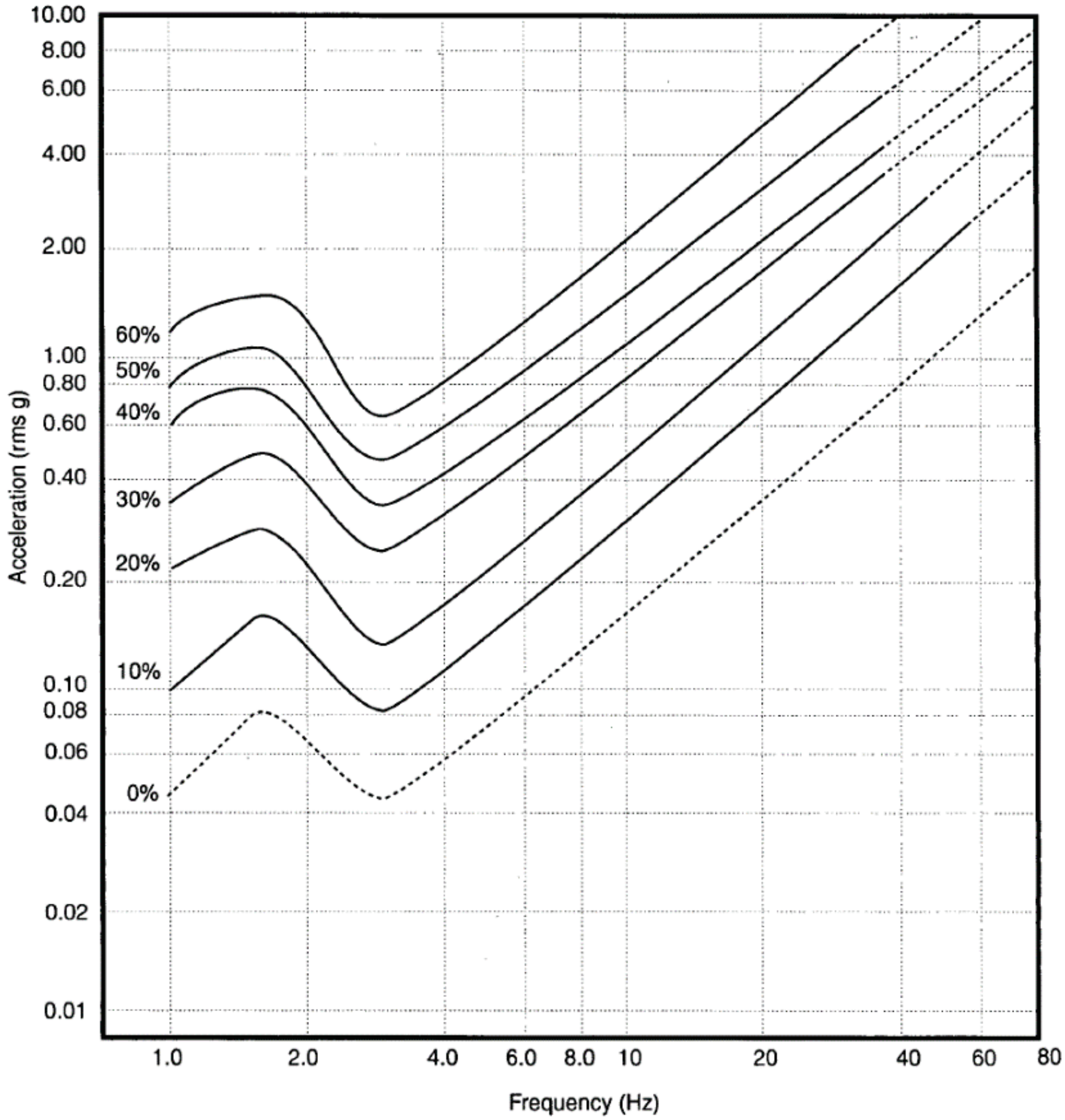


Figure 8.11 Effects on manual tracking by observed vibration characteristics (ISO in NUREG/CR-5680, Echeverria et al., 1994)

8.2.5 Lighting

Echeverria et al. (1994) considered poor lighting effects on reading, inspection, and general visibility. The important characteristics of light—and how those characteristics are measured—are described by Echeverria et al. (1994) and summarized as follows:

- Light intensity is energy radiated in all directions from a light source, measured in lumens.
- Illuminance is the amount of light striking an object that decreases with distance from the bulb and is measured in lux.

- Luminance is the energy reflected off an object, which humans perceive as brightness. It does not decrease with distance.

In addition to these properties of light, Echeverria et al. (1994) noted that several properties of an object being viewed are also important: contrast (i.e., the ratio of the luminance of an object and luminance of the background), the size of the object, and the color of the object. Echeverria et al. also noted large differences in visual acuity across individuals, including a distinct decrease in visual acuity with age.

During a flood of interest, MAs could be performed outside the plant, possibly in unsheltered or semi-sheltered locations, in settings with opportunities for greater lighting issues. Light levels and visibility could be highly variable at unsheltered or semi-sheltered locations, such that individual MAs could be affected differently. Poor visibility could also occur in combination with other ECs. This literature review includes the effects of poor lighting and reduced visibility due to low ambient outdoor light levels, as well as precipitation, and wind.

8.2.5.1 Research Literature Base

Lighting quality and intensity have been well studied for more than a century. Poor lighting has been shown to have significant negative impacts on basic visual perception performance, which adversely affects performance in reading, writing, driving, conducting visual inspections, and performing dependent cognitive tasks that require visual information. Particularly intense exposure (>120,000 lux), or exposure to ultraviolet (UV) lighting can temporarily or permanently damage the retina. The research literature on lighting is reviewed in Volume II, Chapter 6.

8.2.5.2 Mechanisms of Action

Figure 8.12 presents an overview of lighting, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which lighting affects human performance are as follows:

- *Limits of visual perception.* When luminance of targets (e.g., objects, text) by available lighting is insufficient to activate retinal rod receptors, visual perception cannot occur. Likewise, when available light exceeds 100,000 lux, the resulting direct or indirect light incident on the retina (e.g., glare) causes receptors to be overwhelmed, also disrupting vision. An example is dazzle from close lightning. Performance of any physical or cognitive tasks relying on vision suffers when glare occurs.
- *Color perception.* Basic color perception, which is used in distinguishing color coding of wires, for example, requires that the viewed object exhibits a minimum luminance of at least 3 cd/m^2 (Brown, 1951). Below this luminance level, the cone receptors of the retina give way to rods, which specialize in low light vision and cannot discriminate color.
- *Reading and writing.* At illuminances of <100 lux, reading and writing are rendered slower and less accurate. Illuminances between 100–300 lux are adequate for medium contrast/small size discriminations, but up to 1,000 lux are required for prolonged reading of very small, low-contrast text (Weston, 1945, 1953).

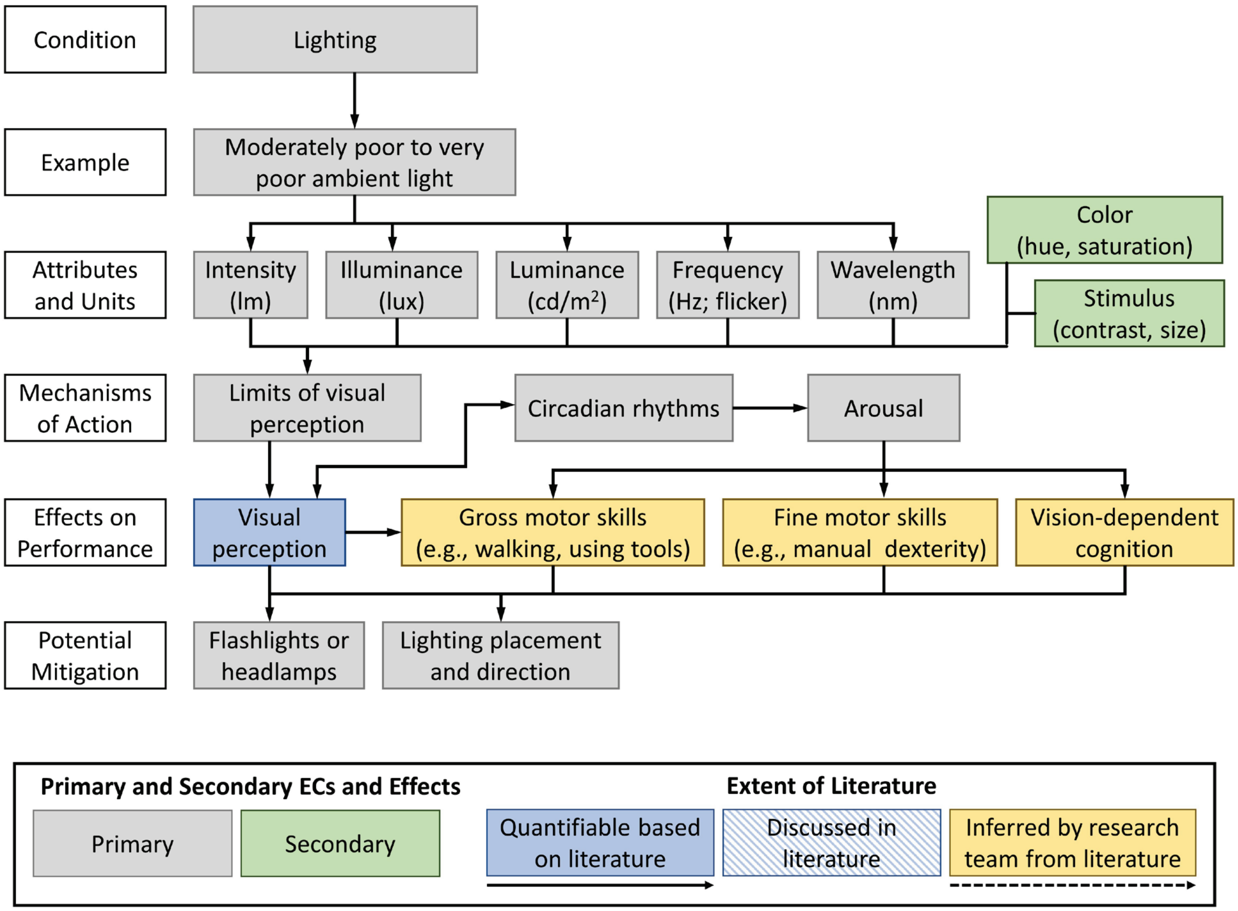


Figure 8.12 Lighting effects overview

- *Visual inspections*. The effect of low illumination on visual inspection performance depends heavily on the intricacy of the inspection. For ordinary inspections where target defects are reasonably large (e.g., fence sections blown away), illuminance below 500 lux may lead to increased time and errors, whereas for inspection of tiny defects in cluttered surrounds, illuminance under 2,000 lux may lead to failure in the detection of defects (See, 2012).
- *Alertness.* The alertness encouraged by higher intensity and short wavelength light has been shown to enhance the performance of a variety of cognitive tasks, including those requiring sustained attention and working memory, speed and concentration, and even improved subjective mood and well-being (Alkozei et al., 2016; Beaven & Ekström, 2013; Borisuit et al., 2015; Chellappa et al., 2011; Keis et al., 2014).
- *Fine motor skills.* Fine motor skills may be disrupted when illumination adversely affects perception, accuracy of inspections, and/or alertness.
- *Gross motor skills*. Both insufficient and excessive illuminance can negatively affect gross motor tasks, increasing the time required to complete tasks and/or increasing errors. For example, if illuminance is too low during a trench digging task, workers may slow down to assure that the tool is placed correctly (e.g., shovel placement, stroke depth). Under time pressure, this could result in poor motor task quality and/or increase the probability of accidents.

The relative impacts of lighting effects on individual performance demands may be assigned for a nominal flooding event as illustrated in Table 8.14. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the attempted reading of displays at night on an exposed platform that is indirectly illuminated by a nearby halogen lamp on a 15 ft high post. The effects of subthreshold/intense lighting have their primary effects on sensation and visual recognition, and to the extent each of the remaining performance demands have visual perception as a precursor (straightforward: reading and writing; situation-specific: command and control with heavy visual component – e.g., involving quick, continuous assessment of several displays, assessment of visual field while driving, and making decisions on maintenance deployments).

8.2.5.3 Summary of Research Literature Review Results

A detailed review of the research literature on lighting is presented in Volume II, Chapter 6. Plots and tables related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
  - Recommendations for illumination levels for various visual activities have been established (Table 8.15; see Volume II, Table 6.2 (DiLaura et al., 2011)).
- Thresholds, measures for success
  - When the luminance of an object is less than **3.426 × 10-6 cd/m^2**, light stimulus is insufficient to activate the retina's rod (low light) receptors, thus **preventing perception of the stimulus** (Figure 8.13; see Volume II, Figure 6.5 (Hood & Finkelstein, 1986))
  - Particularly intense exposure **(>120,000 lux)**, or exposure to UV lighting can **temporarily or permanently damage** the retina.
  - Luminance levels **below a fraction of 1 lux** are insufficient to activate the retina's rod (low light) receptors, thus **preventing perception** of the stimulus.
  - **Lighting above 1 lux but below 50 - 100 lux** is likely **to slow simple visual task speed** in average workers (Figure 8.14; see Volume II, Figure 6.6 (e.g., Tinker, 1939; Weston, 1945, 1953)).
  - At flicker frequencies **above about 50 Hz,** light sources appear to be constantly on, with **no overt flicker** perception (Lehman & Wilkins, 2014). However, some individuals can still be afflicted with motion sickness symptoms by flicker rates **up to nearly 1,000 Hz** (Figure 8.15; see Volume II, Figure 6 7).
- Qualitative measures
  - Subjective mood, alertness, concentration, and well-being are enhanced by even brief exposures to short wavelength light.

Table 8.14 Summary of lighting effects on performance and relative impact of environmental conditions by performance demands[(a)]. Illustrative valuations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Lighting on Performance	Impact of Lighting on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Alertness, Visual Performance, Visual Inspection, Color Perception	Med
Sensation and visual recognition	Visual Performance, Visual Inspection, Color Perception, Alertness	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Visual Performance, Color Perception, Alertness	High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Visual Performance, Alertness	High
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Visual Performance, Alertness	High
Gross motor skills – heavy and light	Visual Performance, Alertness	Med
Other neurophysiological functions	Visual Performance, Alertness	Med
Teamwork		
Reading and writing	Reading & Writing, Visual Performance, Alertness	High
In-person and electronic oral communication	Alertness, Visual Performance	Med
Cooperation, crew interaction, and command and control	Visual Performance, Alertness, Color Perception, Visual Inspection	

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involved the attempted reading of displays at night on an exposed platform that is indirectly illuminated by a nearby halogen lamp on a 15 ft high post.

8.2.5.4 Quantitative Plots and Tables

This section details plots and tables identified in the summary of research literature review results.

Table 8.15 Recommended illumination by activity

Type of Activity	Range of Illuminance (lux)
Public spaces with dark surroundings	20-30-50
Simple orientation for short, temporary visits	50-75-100
Working spaces where visual tasks are only occasionally performed	100-150-200
Performance of visual tasks of high contrast or large size	200-300-500
Performance of visual tasks of medium contrast or small size	500-750-1000
Performance of visual tasks of low contrast or very small size	1000-1500-2000
Performance of visual tasks of low contrast or very small size over a prolonged period	2000-3000-5000
Performance of very prolonged and exacting visual tasks	5000-7500-10000
Performance of very special visual tasks of extremely low contrast and small size	10000-15000-20000

Source: Illuminating Engineering Society; DiLaura et al., 2011

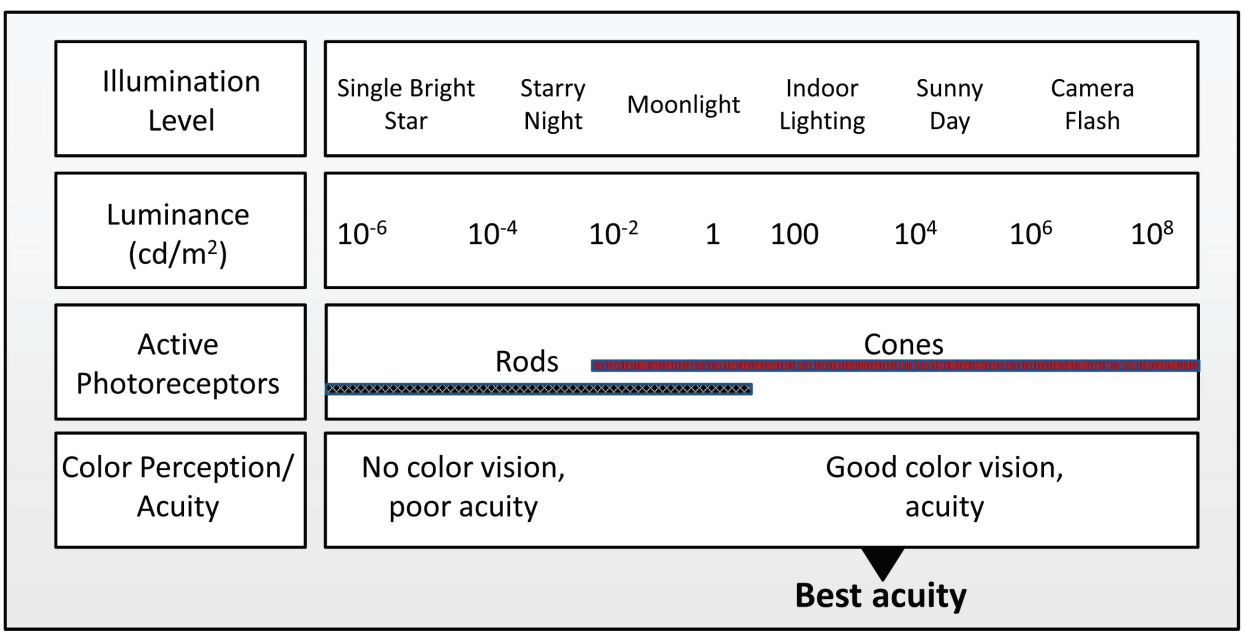


Figure 8.13 Visual perception response at different illumination/luminance levels (after Hood & Finkelstein, 1986)

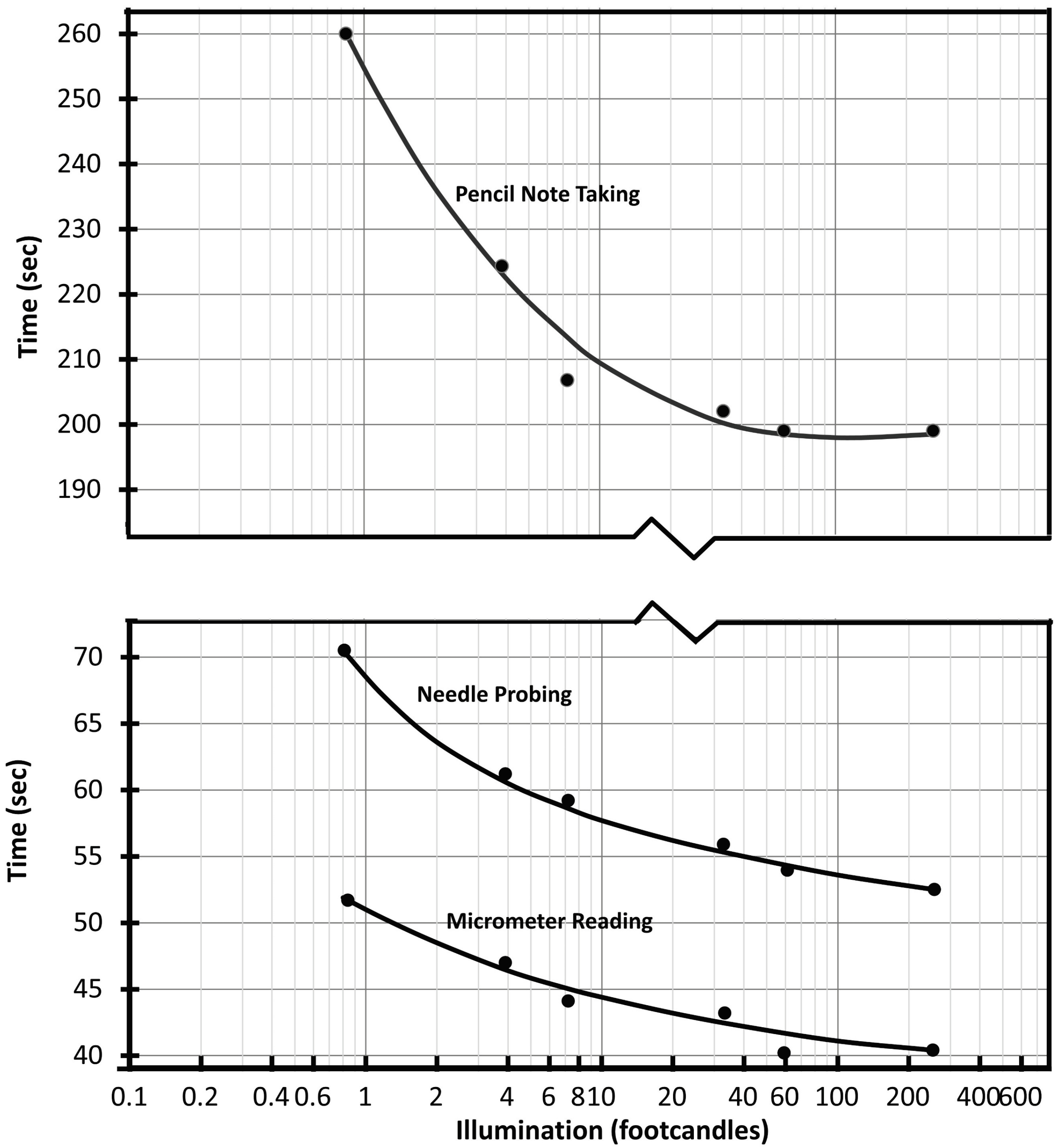


Figure 8.14 Relationship between illumination and task completion time (NUREG/CR-5680, Echeverria et al., 1994)

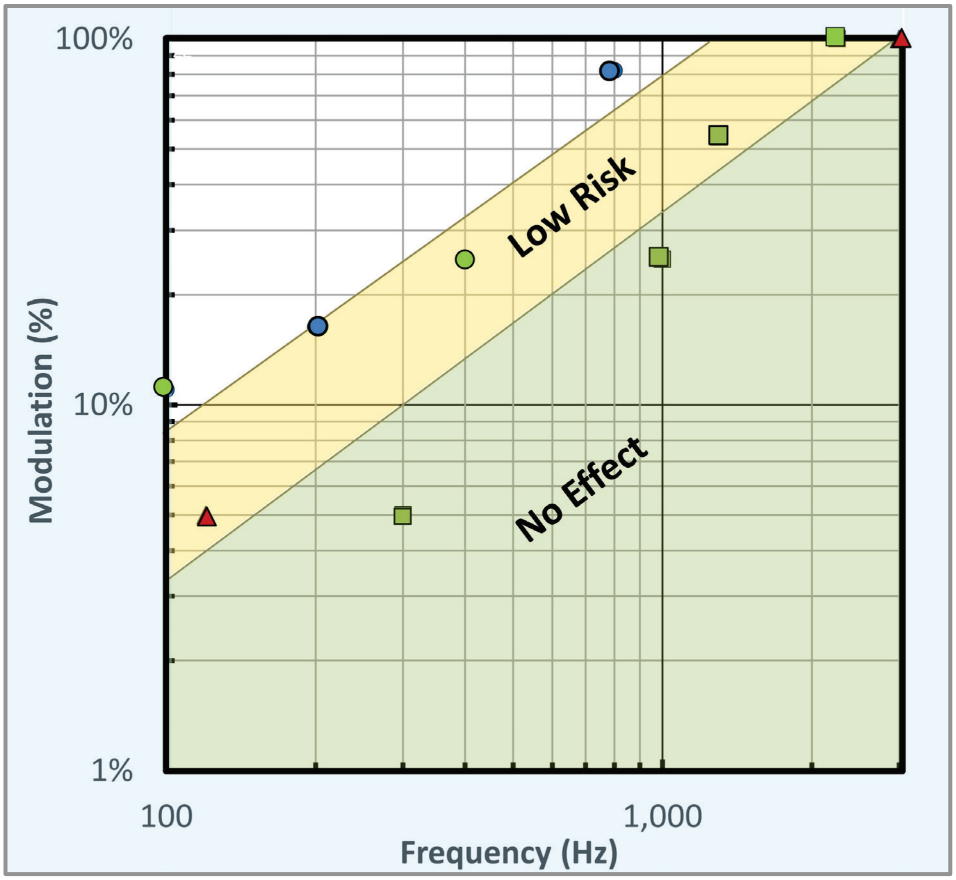


Figure 8.15 Summary of flicker effects from multiple studies (adapted from Lehman & Wilkins, 2014). The low-risk (orange) and no-observable-effect (green) regions for flicker as a function of the frequency and modulation percentage. The line Mod% =0.0333*$f_{flicker}$ separate the no-observable-effect and low-risk regions, and the upper margin of the low-risk region is given by the line Mod% =0.08*$f_{flicker}$.

8.2.6 Humidity

Absolute humidity is defined as the amount of water vapor contained in a volume of air and is generally expressed in grams per cubic meter (gm/m^3). What people perceive as humidity is the "relative humidity," or the ratio of the absolute humidity to the possible maximum, which is a function of air temperature, commonly expressed as a percentage. As detailed in Volume II, Chapter 2, Heat, humidity strongly influences perception of heat and is usually considered in the research literature regarding the physiological effects of temperature.

Echeverria et al. (1994) did not consider humidity separately from heat and cold, but in this report the research team treated humidity as a separate EC because it may have effects during a flooding event, such as fogging instruments, or condensation on glasses and tools, that differ from effects in relatively sheltered environments.

8.2.6.1 Research Literature Base

The effects of humidity are chiefly addressed in the literature as part of heat (see Section 8.2.1 but especially in Volume II, Chapter 2) or cold (see Section 8.2.2, but especially Volume II, Chapter 3). Because they are difficult to study independently of one another, the degree to which humidity is responsible for performance decrements separately from heat and cold cannot be determined from the available research literature. Indeed, many, if not most, contemporary authors argue that humidity should be considered an integral part of combination measures of temperature, wind, and humidity (e.g., WBGT).

8.2.6.2 Mechanisms of Action

Figure 8.16 presents an overview of humidity, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which humidity affects human performance are as follows:

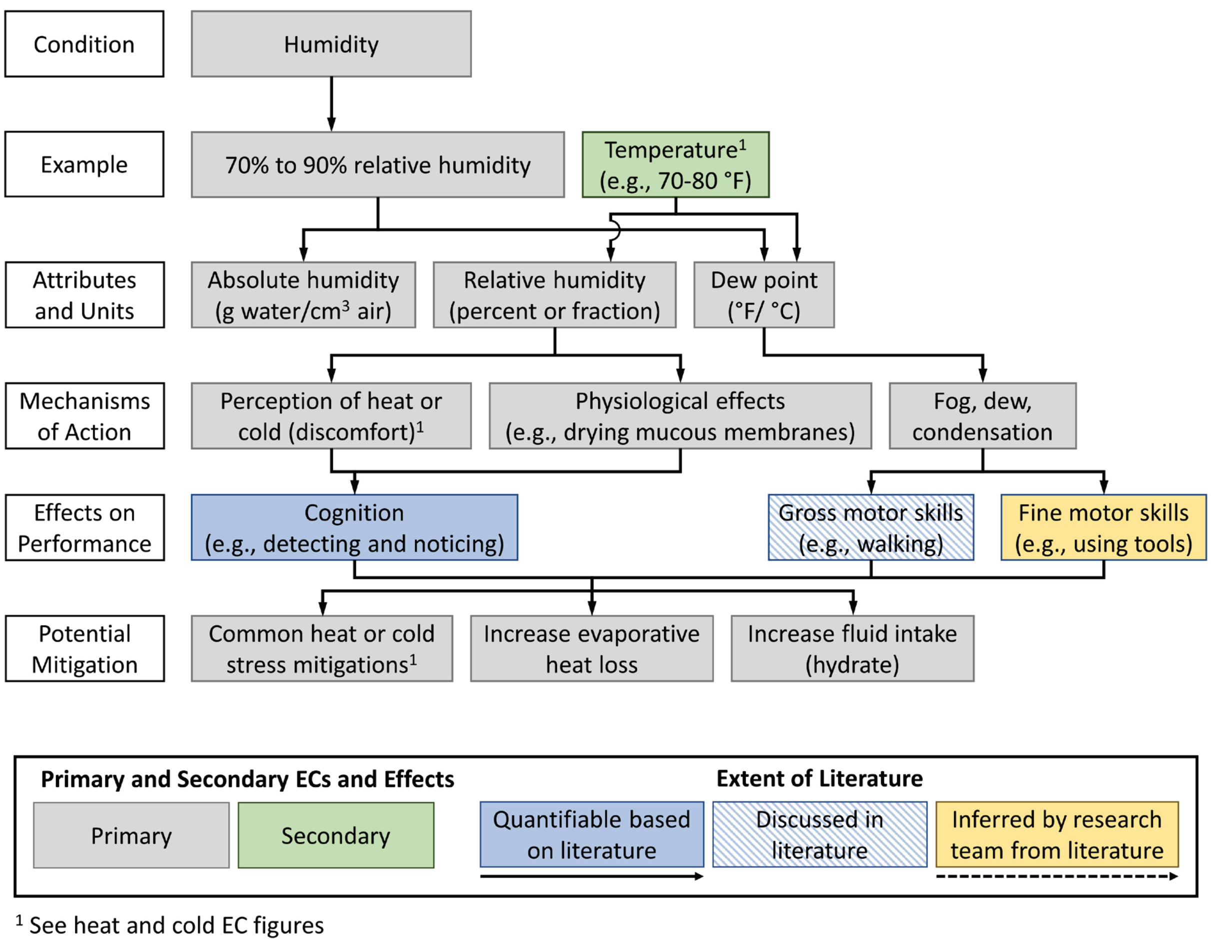


Figure 8.16 Humidity effects overview

- *Perceptions of heat, cold, and discomfort.* High or low humidity has clear impacts on human perception of heat (e.g., Section 8.2.1 and Volume II, Chapter 2) and cold (e.g., Section 8.2.2 and Volume II, Chapter 3). High humidity slows the evaporation of sweat, an important cooling mechanism for the body (Masterton & Richardson, 1979). Hence, higher humidity is related to reduced heat tolerance (and risk of hyperthermia), as well as higher subjective discomfort, and risk of performance decrements, especially for manual vs. sedentary tasks. In cold weather, high humidity enhances heat transfer away from the body, enhancing perceptions of cold, and increasing the potential for hypothermia. Low humidity can also cause discomfort, especially when accompanied by wind, by irritating eyes, drying skin and mucus membranes, and leading to dehydration from fluid loss during exhalation and sweating.
- *Optical fogging/slipperiness*. High humidity leads to condensation of moisture onto walking and other surfaces. Condensation of fog onto eyewear and other glass, plastic, and other surfaces can reduce optical transparency and adversely affect dependent visual tasks and require frequent cleaning. It can also "wet" surfaces such as the pavement, the ground, and worker skin, clothing, and equipment making them "slippery" (e.g., Volume II, Chapter 11, Ice and Snowpack).

8.2.6.3 Broad Effects on Performance

Research has shown that humidity affects human performance in the following ways:

- *Discomfort/distracted attention and judgment*. Longer term exposure to uncomfortable, high humidity environments is associated with sleep difficulties, and physical, perceptual, and cognitive performance due to fatigue. The discomfort associated with both high (see Volume II, Chapter 2, Heat) and low humidity (see Volume II, Chapter 3, Cold) may exacerbate the subjective experience of heat/cold, and consume attentional resources, resulting in performance decrements, especially for complex cognitive tasks (e.g., Colquhoun, 1971).
- *Visual recognition and discrimination.* When relative humidity approaches 100 percent, secondary ECs, especially fog may negatively affect activities requiring vision, especially those involving moving vehicles, although obscured vision may also hamper walking.
- *Mobility of personnel on foot/operating vehicles*. Several lines of field evidence show that high humidity slows walking speed, possibly due to increased slipperiness of walking surfaces but also due to discomfort. It can also affect vehicle control through some of the same mechanisms, because motorists tend to slow down in response to encountering slipperiness, which may be due to humidity.

The relative impacts humidity has on individual performance demands may be assigned for a nominal flooding event task as illustrated in Table 8.16. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves daytime flood protection and mitigation coordination efforts in a partially covered command center. The performance impacts of high humidity are of two primary types: (1) gross motor impacts – walking or driving effects related to associated slipperiness and (2) broad cognitive impacts based on perceptual difficulties from fogging of eyewear and displays as well as limited cognitive resources due to discomfort.

Table 8.16 Summary of humidity effects on performance and relative impact of environmental conditions by performance demands[a]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Humidity on Performance	Impact of Humidity on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Discomfort/Distracted Attention and Judgment; Visual Recognition and Discrimination	High
Sensation and visual recognition	Discomfort/Distracted Attention and Judgment; Visual Recognition and Discrimination	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Discomfort/Distracted Attention and Judgment; Visual Recognition and Discrimination	Med
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Discomfort/Distracted Attention and Judgment; Visual Recognition and Discrimination	Med
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Vehicle Mobility	Med
Gross motor skills – heavy and light	Foot/Vehicle Mobility	Med
Other neurophysiological functions	-	Med
Teamwork		
Reading and writing	Visual Recognition and Discrimination	High
In-person and electronic oral communication	Discomfort/Distracted Attention	Low
Cooperation, crew interaction, and command and control	Discomfort/Distracted Attention and Judgment; Visual Recognition and Discrimination	Med

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves daytime flood protection and mitigation coordination efforts in a partially covered command center.

8.2.6.4 Summary of Research Literature Review Results

A detailed literature review of humidity is presented in Volume II, Chapter 7. A plot related to this summary is in the following section. Insights from that review are as follows:

- Quantitative measures
  - Quantitative effects of humidity are rare in the current literature.
- Thresholds, measures for success
  - The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) **recommends relative humidity levels between 30 and 70 percent to**

maintain comfort in work environments (Baughman & Arens, 1996). Relative humidity levels **above 70 percent may be associated with wetting,** whereas **conditions either above or below the 30 to 70 percent range can lead to discomfort** and, in extremes, health problems.

  - The effect of relative humidity on temperature has been quantified by NOAA/NWS (2014a) as combinations of temperature and relative humidity for which heat disorders are likely in terms of caution and danger zones (Figure 8.17).

- Qualitative measures
  - Discomfort is hypothesized to be a component of many environmental effects on cognitive performance; worker comfort should be addressed whenever the required tasks have a strong cognitive component.

8.2.6.5 Quantitative Table

This section shows a table identified in the summary of research literature review results.

Temperature (°F)

Relative Humidty (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	131	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure of Strenous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Figure 8.17 Risk of heat disorders based on heat and humidity (NOAA-NWS, 2014a)

8.2.7 Wind

Wind is the movement of air from high pressure to low pressure areas, with a greater pressure gradient resulting in stronger winds. Wind speed or strength, is measured, usually using an anemometer, in miles per hour (mph), meters per second (m/s) or knots (one nautical mph = 1.852 km/h = 1.15078 mph). Winds are also characterized as being “sustained” (i.e., steady over time) or as” wind gusts” (i.e., short peaks in wind speed). There are several scales for characterizing wind forces.

The NWS describes a “gale” as sustained surface winds 39 to 54 mph; “high” wind as being 40 mph or higher sustained for 1 hour or 58 mph or greater for any duration; and “extreme” wind as 80 mph or greater for any duration. At the same time, the criteria for NWS wind advisories and warnings vary somewhat by region. Broadly though, a typical wind advisory level would be 31–39 mph sustained for 1 hour or between 46 and 57 mph for any duration, and a typical high wind warning would be 40 mph or higher sustained for 1 hour or 58 mph or greater for any duration. The Beaufort Scale (ASCE, 2004) is another system for characterizing wind speeds shown in Table 8.19.

The common environmental metrics (described above) are not necessarily the most appropriate metrics for characterizing the effects of human exposure to wind. People tend to feel the peak gust speeds the most, and both wind speed and its rate of change tend to be involved in the assessment of impact. Wind speed tends to be faster at ground level and more turbulent in the spaces between tall buildings. Documented wind effects include thermal discomfort, difficulty standing or walking, changes in acoustics, and changes in visibility.

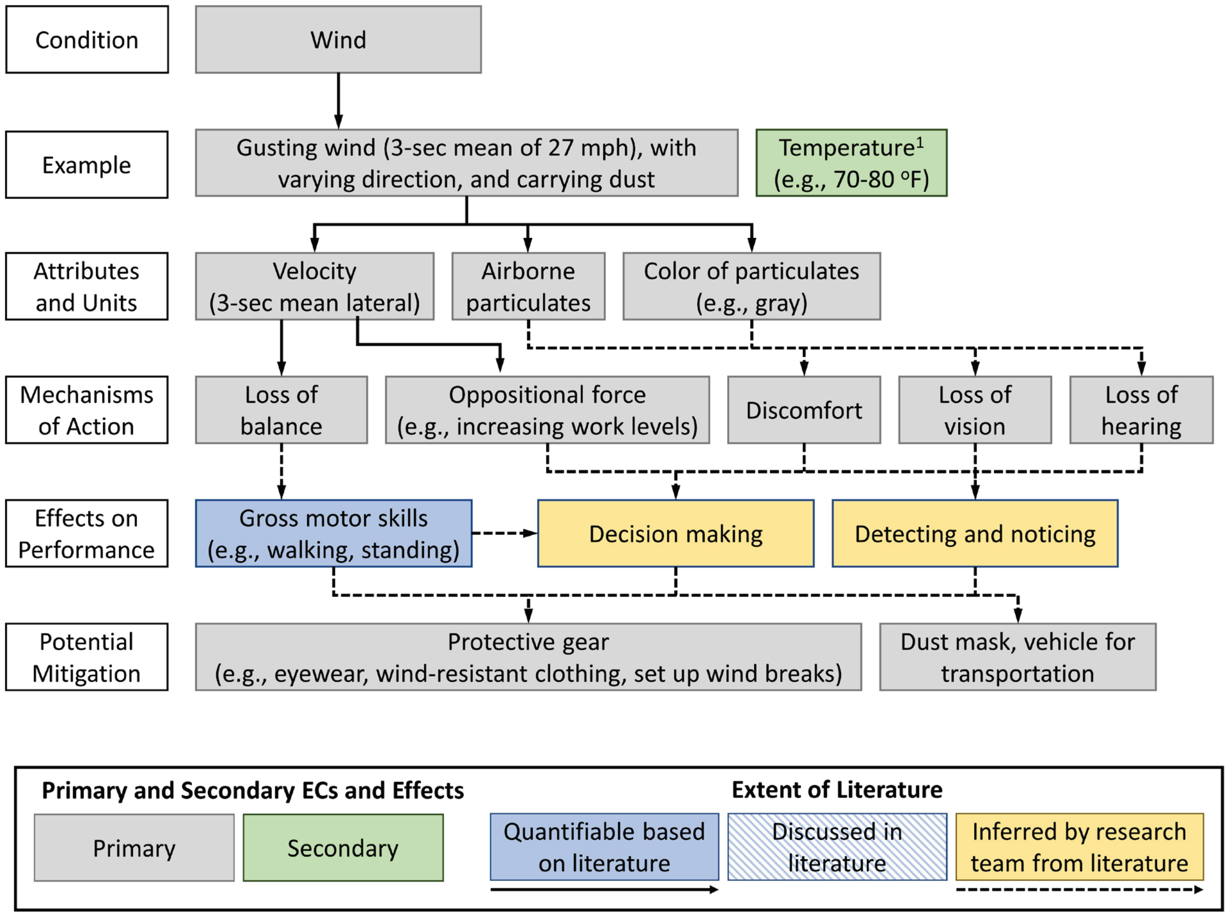
8.2.7.1 Research Literature Base

The formal literature addressing wind’s effects on worker performance is limited, and almost exclusively focused on safety concerns. Indeed, the majority of research regarding wind has focused on human instability, or loss of balance, although wind has a widely acknowledged adverse effect on visual performance (e.g., from gust or dust) and on voice and electronic communications.

8.2.7.2 Mechanisms of Action

Figure 8.18 presents an overview of wind, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which wind affects human performance are as follows:

- *Force applied to self (direct) and/or other flying objects (indirect).* A potential for toppling and possible injury exists under windy conditions. Toppling is dependent upon mechanical moment instability variables (as with Moving Water, Volume II, Chapter 10), including whether the individual is standing or walking, lighter or heavier, and/or wearing form fitting or loose clothing (e.g., Jordan et al., 2008).
- *Distraction/arousal due to perception of risk*. In extremely windy environments, an individual’s fear of the situation, both direct and indirect, may use cognitive resources, as is seen with several other ECs (e.g., heat, cold, standing and moving water). This has a potential for wide ranging impacts on complex skills, fine motor control, coordination, steadiness, as well as general cognition.



[1] See heat and cold EC figures

Figure 8.18 Wind effects overview

8.2.7.3 Broad Effects on Performance

Research has shown that wind affects human performance in the following ways:

- *Toppling and gross motor skills.* The effects of wind can include difficulties in walking, leaning over to lift and lifting objects (particularly when there are large “sail effects,” as well as restricted range of motion), and limited dual hand activities (the last arguably because of the requirement to hold onto stationary supports). In extremes, any gross motor performance (e.g., standing or walking) may be significantly affected, as the body approaches toppling. The forces leading to toppling increase the probability of injuries from falls.
- *Fine motor skills; cognition*. Although research is lacking on wind’s effects on fine motor and higher-level cognitive performance demands, by logical extension, it is anticipated that they would be adversely affected when the more basic performance demands (e.g., standing and walking) become challenged by wind. Because of the anxiety effects of wind, impacts on higher level performance demands have not been examined quantitatively, though they are a candidate for future research.

- *Visual performance.* Wind carried dust (or rain, etc.) can impair visual detection, recognition of far objects, and reading of nearby dust covered displays and written materials. Even clear air gusts that momentarily hit the eyes past eyewear corners or face shields can lead to periods of uncontrolled blinking and visual disruption.
- *Verbal and electronic communication.* Wind noise can obscure direct voice communications as well as communications over electronic devices.

The relative impacts of wind may be assigned for a nominal flooding event task as illustrated in Table 8.17. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves attempts to erect flooding barriers in the early stages of a thunderstorm that include rain and occasional gusts of near gale force wind. The research literature primarily supports effects on gross motor skills through toppling. Toppling is also assumed to interrupt all possible performance demands, because they become impossible when this occurs. Although there is little direct evidence of wind's effects on cognitive performance through distraction/arousal processes, these processes would logically occur during extreme wind exposure, and thus may operate similarly on cognition.

8.2.7.4 Summary of Research Literature Review Results

A detailed review of the research literature on wind is presented in Volume II, Chapter 8. Tables related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
  - The expected effects on an individual's locomotion speed can be calculated for different wind speeds (Table 8.18; see Volume II, Table 8.2, Chapter 8, Wind (Murakami & Deguchi, 1981)).
- Thresholds, measures for success
  - Table 8.18 (Volume II, Table 8.2) also includes stability/perception of risk limits, where **winds of greater than 5 m/s** can be expected to have some **effect on stability and perception of risk for pedestrians** (Murakami & Deguchi, 1981).
  - Winds **greater than 30 mph (25 knots)** are considered to have **moderate degradation**[1] on engineering personnel **and greater than 45 mph (40 knots) to cause severe degradation** in efforts by engineering personal acting in military tactical operations (U.S. Army, 1992).
- Qualitative measures
  - Descriptive terms have been identified for different ranges of wind speed (e.g., light breeze, near gale; Table 8.19; see Volume II, Table 8.1 (ASCE, 2004)).

8.2.7.5 Quantitative Tables

This section details tables identified in the summary of research literature review results.

[1] U.S Army Field Manual defines moderate performance impact as normal effectiveness reduced 25-75% and severe impact as normal effective reduce to 0-25%

Table 8.17 Summary of wind effects on performance and relative impact of environmental conditions by performance demands [a]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Wind on Performance	Impact of Wind on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Visual performance, Toppling and Gross Motor Performance; Attention-Distraction, Cognition[(b)]	High
Sensation and visual recognition	Visual Performance, Toppling; Cognition*	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Cognition[(b)] and Toppling	Med-High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Toppling, Distraction and Attention; Cognition[(b)]	Med-High
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Fine Motor Skills	Med/High
Gross motor skills – heavy and light	Toppling and Gross Motor Performance	High
Other neurophysiological functions	Risk Perception and neurochemical	Med-High
Teamwork		
Reading and writing	Toppling	High
In-person and electronic oral communication	Cognition[(b)]	Med/High
Cooperation, crew interaction, and command and control	Toppling; Cognition[(b)]	High

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves attempts to erect flooding barriers in the early stages of a thunderstorm that include rain and occasional gusts of near gale force wind. (b) Inferred.

Table 8.18 Outdoor worker and in-vehicle wind limits

UNSHELTERED PERFORMANCE LIMITS			
Murakami-Deguchi Limits for qualitatively evaluating (stability and perception of risk) wind effects on pedestrians where *U* (m/s) is the instantaneous wind speed average over 3 s			
		English Units	**Metric Units**
No Effect		$U \leq 16.4$ ft/s	$U \leq 5$ m/s
Some Effect		16.4 m/s > $U \leq 32.8$ ft/s	5 m/s > $U \leq 10$ m/s
Serious Effect		32.8 m/s > $U \leq 49.2$ m/s	10 m/s > $U \leq 15$ m/s
Very Serious Effect		$U > 49.2$ ft/s	$U > 15$ m/s
These may be recast to reflect a quadratic function with approximately a doubling (~2.25) of the proportional-increase (*R*) in time required for walking, carrying, and manual-handling (e.g., fine motor) at 7.5 m/s to an ~9-fold increase at 15 m/s			
		English Units	**Metric Units**
$R = 1$	for	$U \leq 16.4$ ft/s	$U \leq 5$ m/s
$R = (U/5)^2$, *U* in m/s	for	$U > 16.4$ ft/s	$U > 5$ m/s
WITHIN VEHICLE LIMITS Rodriguez et al. (2014; 2015) explored high-wind vehicle control performance for cars, ambulances, and buses. This suggested that—neglecting debris—vehicle low speed movements would be possible during hurricane wind speeds (74–95 mph), but clearly impossible in high category storms.			

Table 8.19 Beaufort scale of wind as used on land and estimating speed

Beaufort Number	Descriptive Term	Speed (km/hr)	Speed (~mi/h)	Specification for Estimating Speed
0	Calm	< 2	< 2	Smoke rises vertically.
1	Light Air	2–5	2–3	Direction of wind shown by smoke drift but not by wind vanes.
2	Light Breeze	6–11	4–7	Wind felt on face; leaves rustle; ordinary vane moved by wind.
3	Gentle Breeze	12–19	7–12	Leaves and small twigs in constant motion; wind extends light flag.
4	Moderate Breeze	20–29	12–18	Raises dust and loose paper; small branches are moved.
5	Fresh Breeze	30–39	19–24	Small trees in leaf begin to sway; crested wavelets form on inland waters.
6	Strong Breeze	40–50	25–31	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty.
7	Near Gale	51–61	32–38	Whole trees in motion; inconvenience felt in walking against the wind.
8	Gale	60–74	37–46	Breaks twigs off trees; generally, impedes progress.
9	Strong Gale	75–87	47–54	Slight structural damage occurs e.g. to roofing shingles, TV antennae, etc.
10	Storm	88–102	55–63	Seldom experienced inland [except during tornadoes]; trees uprooted; considerable structural damage occurs.
11	Violent Storm	103–116	64–72	Very rarely experienced; accompanied by widespread damage.
12	Hurricane	> 116	> 72	
Note: 10 km/h= 6.21 mi/h				*Source: ASCE, 2004*

8.2.8 Precipitation

Precipitation is a form of liquid, solid, or transitional water falling under the force of gravity (fallen precipitation is addressed later in Chapter 8.2.9, Standing and Moving Water and Chapter 8.2.10, Ice and Snow). Precipitation is associated with several flood causing mechanisms: notably flooding from LIP, riverine flooding, and storm surge flooding. Depending on when and where the actions take place, workers may be exposed to precipitation while performing MAs. Precipitation often takes the form of rain, although snow and sleet are possible in colder months and hail is possible at any time of the year. Precipitation is typically measured in inches of liquid- or solid-phase water (depth per unit horizontal area). The intensity of precipitation is related to its accumulation over a time period (e.g., inches per hour or inches per day). Both the amount and intensity of precipitation are highly variable in time and space. As precipitation falls through air, its primary effects are on visibility, which can impair visual perception, communication, teamwork, and vehicle operation. Once precipitation reaches surfaces, it can affect human performance by causing discomfort and/or injury, wetting equipment or materials, increasing noise levels, creating slippery surfaces, and hindering ease of mobility. All forms of precipitation can contribute to flooding immediately upon reaching the ground, or over a longer period of time as it melts, runs off, and accumulates downstream.

8.2.8.1 Research Literature Base

Precipitation has long been recognized as having adverse effects on exposed outside workers, but systematic research on the effects on work rates and accuracy is sparse. Rather, the empirical study of precipitation effects has been limited primarily to vehicle operation, because the visibility effects can cause automobile accidents and fatalities. Once precipitation reaches the ground or other surfaces, other ECs come into play, such as Standing and Moving Water (see Volume II, Chapter 10), Ice and Snowpack (see Volume II, Chapter 11), and Cold (Volume II, Chapter 3).

8.2.8.2 Mechanisms of Action

Figure 8.19 presents an overview of precipitation, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which precipitation affects human performance are as follows:

- *Reduced visibility and increased workload.* Simulator studies suggest that drivers check their mirrors less frequently and fixate (or visually dwell on an area of the visual field, as measured by an eye tracker) less frequently, but for longer periods, during heavy rain/snow. This suggests that navigating through precipitation—either driving or by extension, on-foot— consumes processing resources. Personnel may have difficulty allocating their attention to the complex tasks of navigation and vehicle operation when precipitation is drawing their attention. There may be increased workload due to wearing rain gear
- *Induced motion*. Precipitation may also affect driving—and by extension, walking—performance through induced motion effects. Induced motion is the tendency to perceive oneself as moving when one is not. Directional precipitation, especially snowfall, can produce this induced motion effect, resulting in individuals committing systematic heading judgment errors while driving (Richman et al., 2000; Royden & Hildreth, 1996; Warren & Saunders, 1995).

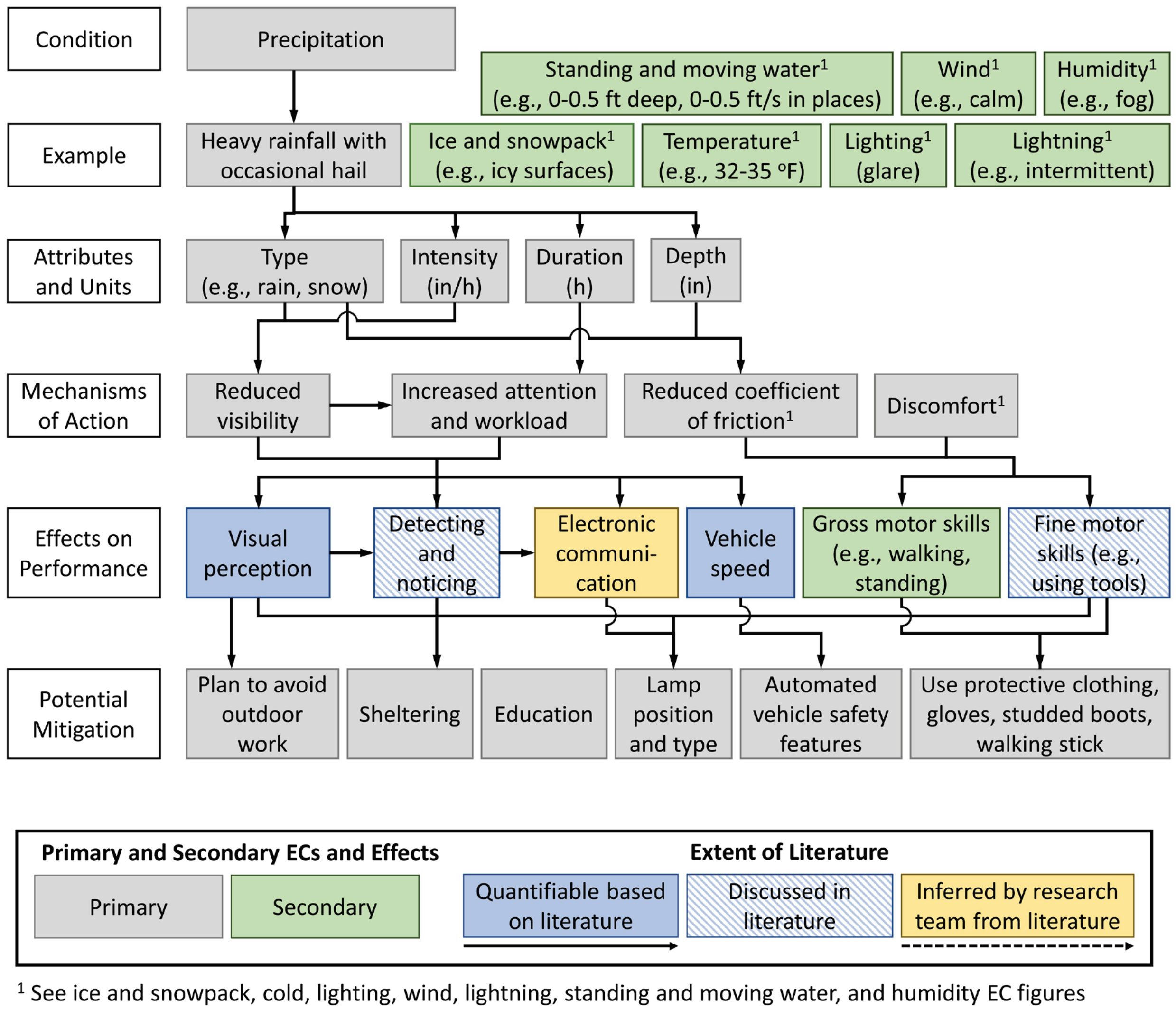


Figure 8.19 Precipitation effects overview

- *Perceptions of risk*. Perceptions of risk, especially the risk of falling and injury, are important psychological factors affecting performance, especially for workers who are less experienced with the threatening conditions. Somewhat remarkably, research on the effects of severe weather conditions (precipitation, standing and moving water, ice and snowpack), though commonly addressing the effects of reduced coefficient of friction (and hence slipperiness), has generally not studied perceptions of risk. Anxiety or fear due to precipitation has the potential to produce additional effects on cognition, based on well-established stress and anxiety mechanisms.
- *Slipperiness.* Once precipitation reaches the ground, it may cause both automobile and pedestrian accidents because it makes surfaces slippery. Slipperiness, a reduction in the coefficient of friction, may occur on sidewalks and roads, as well as on tools (for a detailed discussion of slipperiness, see Volume II, Chapter 11).
- *Discomfort.* Precipitation can produce thermo-regulative discomfort by soaking clothing or wearing protective rain gear (see Volume II, Chapter 2, Cold), and it is often perceived

negatively (though sans thermoregulatory effects), influencing mood, well-being, and even productivity.

8.2.8.3 Broad Effects on Performance

Research has shown that precipitation affects human performance in the following ways: Reduced motor speed, reduced visibility, increased workload, and induced motion effects due to precipitation may reduce free-flow traffic speed due to compensatory automobile driver caution, therefore increasing travel time. Visibility reduced by precipitation can also increase the required reaction distance for traffic signals.

- *Attention, noticing, and visual recognition.* Reduced visibility associated with precipitation also makes signal and signage noticing and reading more difficult (Pisano et al., 2003). Work that relies on distance vision outdoors (e.g., surveying, monitoring outdoor security cameras) may be rendered difficult or inaccurate due to the light attenuation or reflection effects of precipitation.
- *Attention/workload.* Precipitation has both direct and indirect impacts on attention and workload, which has implications for multitasking behaviors such as those required while operating a vehicle. For example, if an individual is attempting to navigate a new route, communicate over a radio, and perform other actions demanding attention, these tasks, the subject's driving performance, or both could be negatively affected. Discomfort of individuals soaked by precipitation or slowed down with the complication of rain gear may also make significant demands of limited attentional resources, negatively impacting other tasks that may tap these resource

The relative impacts precipitation has on individual performance demands may be assigned for a nominal flooding event task as illustrated in Table 8.20. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the operation of a panel van during a thunderstorm, with a requirement to periodically report information about flooding impacts (e.g., impacts on roadway, structures) and coordinate with other team members. The majority of precipitation impacts on human performance relate to the effects on visibility.

8.2.8.4 Summary of Research Literature Review Results

A detailed literature review of precipitation is presented in Volume II, Chapter 9. Plots related to this summary are in the following section. The insights from that review are as follows:

- Quantitative measures
  - The effects of falling rain and snow on free-flow vehicle speeds have been modeled fairly extensively (Figure 8.20; see Volume II, Section 9.5.1, Figures 9.3 and 9.4 (Hranac et al., 2006)).
- Thresholds, measures for success
  - Rainfall at **0.11-0.30 in/hour causes moderate degradation**[2] in personnel movement while heavy snowfall at **rates greater than 0.30 in/hour causes severe degradation** in personnel movement (U.S. Army, 1992).
  - **Light, freezing rain** is described as causing moderate degradation to engineering personnel and vehicles, while **moderate, freezing rain** causes **severe degradation** (U.S. Army, 1992).

[2] U.S Army Field Manual defines moderate performance impact as normal effectiveness reduced 25-75% and severe impact as normal effective reduce to 0-25%

Table 8.20 Summary of precipitation effects on performance and relative impact of environmental conditions by performance demands[a]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Precipitation on Performance	Impact of Precipitation on Perf. Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Attention, Noticing, and Visual Recognition; Attention/ Workload	High
Sensation and visual recognition	Attention, Noticing, and Visual Recognition	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Attention, Noticing, and Visual Recognition	High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Attention and Workload	Med/High
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Reduced Motor Speed	Med/High
Gross motor skills – heavy and light	Reduced Motor Speed	Med/High
Other neurophysiological functions	-	High
Teamwork		
Reading and writing	-	NA
In-person and electronic oral communication	-	NA
Cooperation, crew interaction, & command/control	-	High

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves the operation of a panel van during a thunderstorm with a requirement to periodically report information about flooding impacts (e.g., impacts on roadway, structures) and coordinate with other team members.

- Aside from the Army Field Manual, no thresholds for successful outside work or driving performance were identified.
- Obvious rules such as not attempting to drive when you cannot visually perceive your environment are not practical types of thresholds a because a means of objectively measuring the visibility effects of falling precipitation is not available to most performers of manual actions.

- Qualitative measures
  - Individual differences likely exist in the degree of fear engendered by operating a vehicle (for example) in heavy precipitation. Overly strong or weak fear responses could both be detrimental to performance

8.2.8.5 Quantitative Plots

This section details plots identified in the summary of research literature review results.

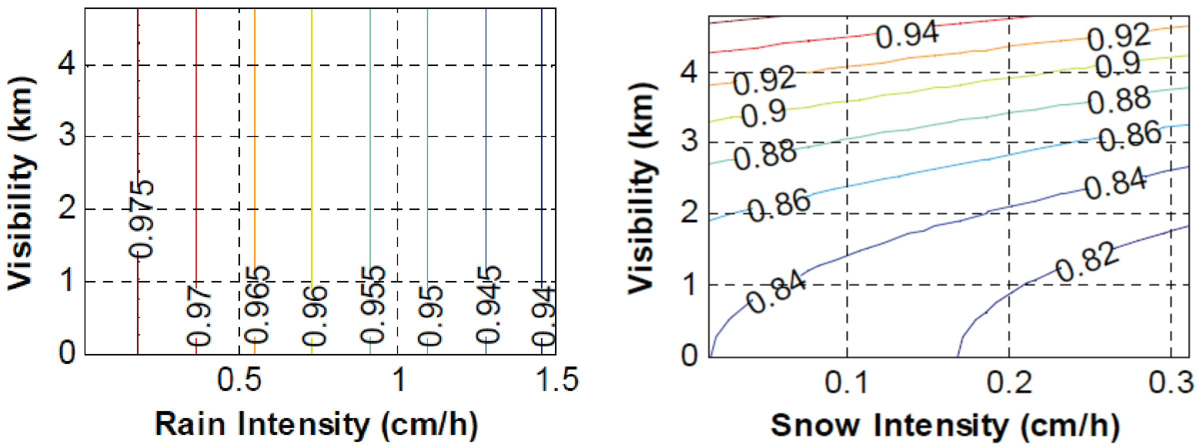


Figure 8.20 Free-flow wheeled vehicle speed reduction under precipitation conditions (Hranac et al., 2006). Left panel: under rain conditions and Right panel: snow conditions (as a ratio to regular speed).

8.2.9 Standing and Moving Water

Personnel may encounter standing or moving water during execution of MAs if floodwaters inundate part of an NPP site. This may occur when (1) precipitation accumulates in depressions (e.g., when an NPP's drainage system is overwhelmed), (2) NPP areas are inundated by offsite floods, or (3) water remains in depressions after floodwaters recede. Standing and moving water attributes have potential effects on the performance of MAs. Specifically, both the depth (m or ft) and velocity (m/s or ft/s) of floodwaters can affect the individual's stability, slowing execution of work, impeding movement, and, under certain conditions, even toppling the person. At the same time, the EPA warns that floodwaters should be assumed to be contaminated by chemical and biological hazards; hence, working in floodwaters requires appropriate protective gear. Noise associated with water flow, or ongoing precipitation, may disrupt communications and teamwork. The turbidity of floodwaters also may affect an individual's ability to walk confidently or perform underwater actions (e.g., lifting submerged items, working on objects that are underwater or partially submerged). The temperature of floodwaters may also have adverse effects on the performance demands required for performing MAs (e.g., by affecting gross and fine motor skills and complex problem-solving skills; see Volume II, Chapter 3, Cold).

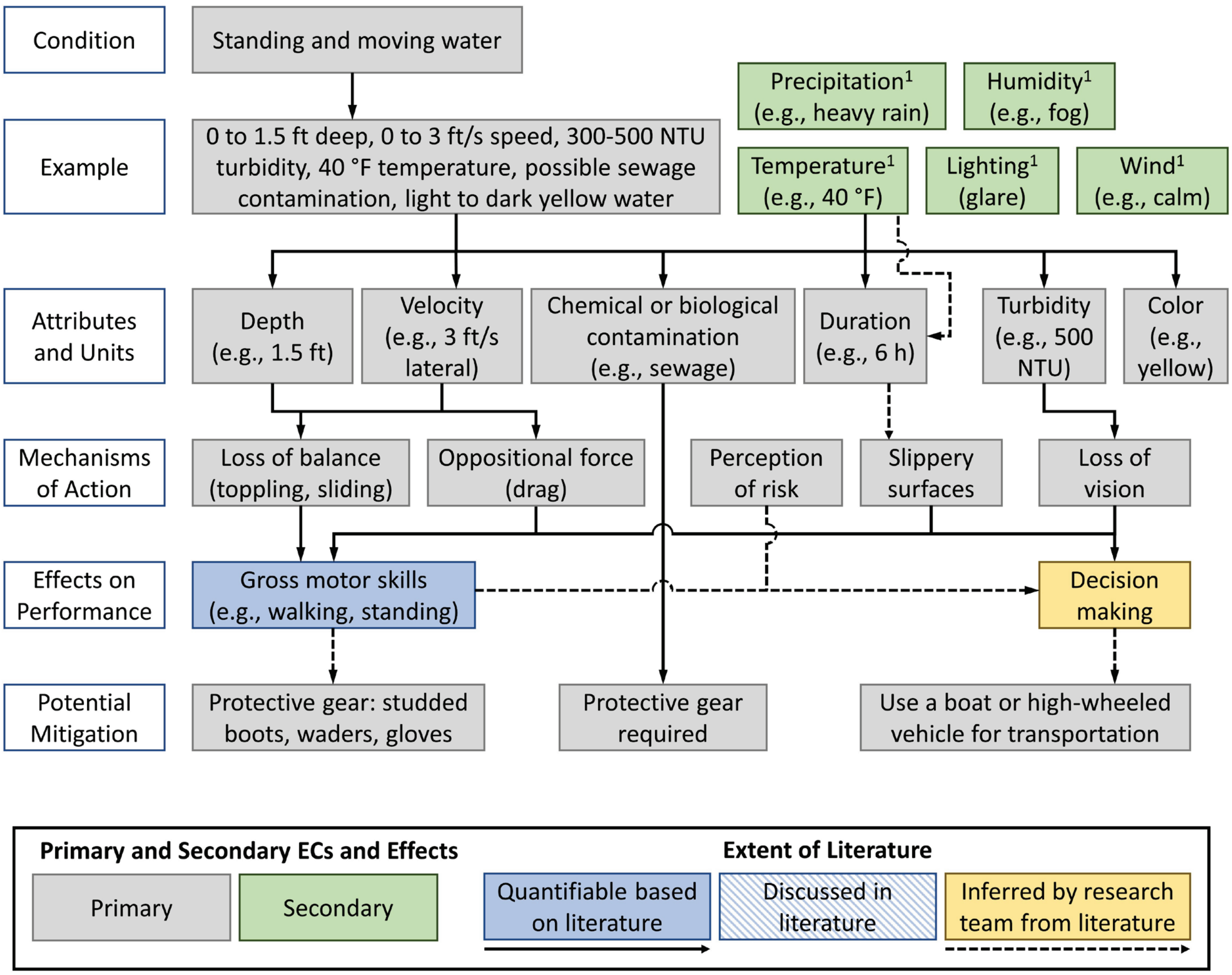
8.2.9.1 Research Literature Base

The formal literature regarding standing and moving water effects on personnel performance is almost exclusively focused on safety concerns. Indeed, the majority of water research attention has been applied to (1) human instability, or loss of balance and toppling, and (2) the related perceptions of risk of toppling. At the same time, though not formally studied, there is widespread appreciation of its related direct effects on the speed of walking and performance of manual handling tasks. There is similar appreciation of related noise effects on communications as well as the potential for inducing hypothermia when working in water.

8.2.9.2 Mechanisms of Action

This section and Figure 8.21 present an overview of standing and moving water, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which standing and moving water affect human performance are as follows:

- *Force applied.* Potential exists for toppling and possibly injury. Toppling is dependent upon mechanical moment instability variables (much as with wind, Volume II, Chapter 8). These variables include whether the individual is standing or walking, is lighter or heavier, and especially whether the individual is wearing or not wearing slip-resistant footwear. Progression can also be slowed by the force of moving or standing water.
- *Noise accompanying moving water.* This may serve to obscure auditory alerts and verbal communications (direct and electronic).



[1] See cold, heat, precipitation, humidity, lighting, and wind EC figures

Figure 8.21 Standing and moving water effects overview

- *Distraction/arousal due to perception of risk.* With increasing depth and velocity, an individual's fear of toppling—both direct and indirect—may act as a sink for limited cognitive resources, as is seen with several other ECs (e.g., wind, heat, cold). Both occasional turbidity blocking bottom hazards and the unknown risks from potential biological-chemical water contamination may also add to situational stress. These altogether have the potential for wide ranging impacts on complex skills, fine motor control, coordination, steadiness, and cognition.
- *Slippery surfaces and loss of vision*. When trying to progress, and recover lost tools or supplies, the slippery surfaces of the ground and wet items can delay the performance of MAs. The inability to see hazards beneath the water increases risk of tripping and may slow progression. Also, delays in MA performance can be caused by an inability to see dropped tools, supplies, or the items that are being worked on.

8.2.9.3 Broad Effects on Performance

Research has shown that standing and moving water affects human performance in the following ways:

- *Toppling and gross motor performance.* Standing and moving water can impede standing and walking and make tasks that require leaning over to lift and lifting objects more difficult (particularly when there are large underwater "sail effects," as well as restricted range of motion, especially with waders or similar water gear). Standing and moving water could also impair dual hand activities (because of the need to hold onto stationary supports or employ a walking stick for stability). In extreme standing and moving water conditions, any gross motor performance (e.g., standing or walking) may be significantly affected as the body approaches toppling.
- *Fine motor skills, cognition*. Although research is lacking on standing and moving water's effects on fine motor and higher-level performance demands, by logical extension, it is anticipated that they would also be adversely affected particularly as the more basic performance demands (e.g., standing and walking) are challenged. Anxiety effects of standing and moving water on higher-level performance demands have not been examined quantitatively, so they are candidates for future research.
- *Visual performance.* Water turbidity can serve to block visual detection or recognition of underwater objects (e.g., a dropped tool or walking hazard).
- *Auditory performance*. The noise associated with moving water can obscure detection or recognition of auditory alerts as well as voice communications (direct and/or electronic).

The relative impacts that standing and moving water have on individual performance demands may be assigned for a nominal flooding event task as illustrated in Table 8.21. The nominal flood event task, arbitrarily chosen solely for illustrative purposes, involves attempts by a two-member crew to erect flooding barriers while exposed to standing and moving water that is 0.3 m deep and is flowing at 0.5 m/s (see Equation 10.2 in Volume II, Chapter 10). Significant water noise affects direct voice communication with a forklift operator placing the barrier components that he had retrieved from the storage area. The literature primarily supports effects on gross motor skills through toppling. Toppling is also assumed to interrupt all possible performance demands, because they become impossible when this occurs. There is indirect research evidence for standing and moving water's effects on cognitive performance through the distraction/arousal processes. These processes would logically occur during extreme exposure, and thus may operate similarly on cognition.

Table 8.21 Summary of moving water's effects on performance and relative impact of environmental conditions by performance demands[a]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Standing and Moving Water on Performance	Impact of Standing Moving Water on Perf. Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Toppling Risk and Attention-Distraction from Noise and Turbidity	High
Sensation and visual recognition	Visual detection (bottom obscuration), Cognition[b]	Med
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Cognition[b]	Med-High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Obscuration of bottom; Distraction and Attention; Cognition[b]	Med-High
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Distraction and Attention with risk of toppling, "body movement with water surges"	Med
Gross motor skills – heavy and light	Toppling and Gross Motor Performance	High
Other neurophysiological functions	Risk Perception and Neurochemical Changes	Med-High
Teamwork		
Reading and writing	Distraction and Attention with risk of Toppling	Med-High
In-person and electronic oral communication	Water Noise	Med/High
Cooperation, crew interaction, and command and control	Distraction and Attention with risk of toppling; Water Noise Cognition[b]	Med-High

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves attempts by a two-member crew to erect flooding barriers exposed to standing and moving water that is 0.3 m deep and is flowing at 0.5 m/s. Significant water noise affects direct voice communication as well as with a forklift operator placing the barrier components that he had retrieved from the storage area.
(b) Inferred.

8.2.9.4 Summary of Research Literature Review Results

A detailed review of research literature on standing and moving water is presented in Volume II, Chapter 10. Plots and equations related to this summary are in the following section. Insights from that review include the following:

- Quantitative measures
  - Locomotion **speed can be calculated for different water depth-speed combinations** (Figure 8.22; see Equation 10.2 in Volume II, Chapter 10 (Xia et al., 2014))
- Thresholds, measures for success
  - A threshold boundary for **minimized risk of toppling** has been derived, based on an engineering model and empirical results (Figure 8.22; see Volume II, Figure 10.3 (Xia et al., 2014)). This threshold boundary **is approximated by PN<0.3 m^2/s**, where PN, the product number, is the product of floodwater depth (m) and velocity (m/s).
- Qualitative measures
  - **Perceptions of toppling risk** have been developed as function of water depth and velocity (e.g. Webster et al., 2013 as noted in Volume II, Section 10.4). Perceptions of the risk of toppling tend to be higher than actual **risk but largely parallel the actual risk boundary** (i.e. approximately product number<0.3).

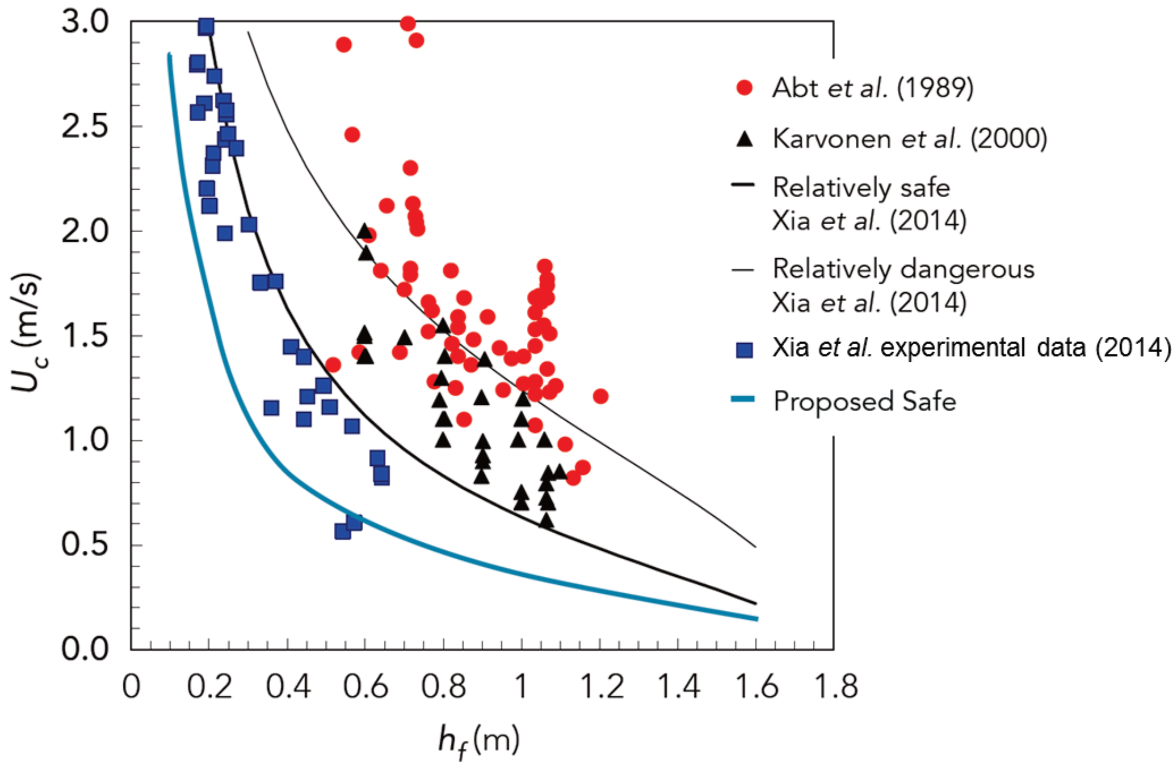


Figure 8.22 Empirical results and guidance for product number toppling effects (Adapted from Xia et al., 2014). Includes proposed safe guideline (bottom-most curve in blue).

8.2.9.5 Quantitative Equations and Plot

This section details a plot and equations identified in the summary of research literature review results.

Maximum values for safe work (shown as a blue line in Figure 8.22) can estimated as a threshold safe walking velocity(m/s), using the boundary equation:

$$SWV = U_c - V \tag{8-2}$$

where U_c is the velocity (m/s) for depth of flow h_f (m) and $V < U_c$ is the prevailing floodwater velocity (m/s). For a travel distance x_{travel} and a typical walking speed $V_{typical}$, the time delay, Δt, in progression can be evaluated as

$$\Delta t = t_{typical} - t_{SWV} = \frac{x_{travel}}{V_{typical}} - \frac{x_{travel}}{SWV}. \tag{8-3}$$

8.2.10 Ice and Snowpack

Ice and snowpack are two different forms of frozen water. Of these, ice is a layer or mass of frozen water, typically presenting a slippery surface that may affect performance. Snow, on the other hand, is typically less compressed, particularly when freshly fallen. Surface slipperiness, especially on ice, has been shown to substantially degrade the speed and safety of both gross and fine motor tasks (e.g., Grönqvist, Abeysekera, et al., 2001; Holmér et al., 2012). Tasks that are subject to potential impairment include walking and carrying, particularly on sloped surfaces, stairs, and ladders (where handrails and steps may both be iced). Performance of manual handling tasks (e.g., pushing, pulling, and lifting) also have been shown to be substantially impaired, particularly on sloping surfaces. Performance of fine motor tasks—especially gloved—may also be markedly impaired, especially where objects, tools, and contact surfaces are ice covered.

Snowpack refers to snow accumulated on the ground or other surfaces. Depth (in. or cm), age (days), density (lb/ft^3 or kg/m^3), and water equivalent (in. or cm) are important characteristics of snowpack. Another important characteristic of snowpack is that it reflects light, which is why it appears “white.” Reflected light can result in glare in sunshine or flat light (inability to distinguish shapes or shadows) under overcast skies. Snowpack persists with low temperatures and its characteristics change with time. Several ways that snowpack could affect MAs are by slowing or hampering outdoor travel, hiding obstacles and landmarks, creating icy surfaces during melt/freeze cycles, or creating glare. If significant snow is cleared from roads and other paths of travel, it would be piled up elsewhere, where it would likely contribute to runoff volume, affect (constrict) runoff flow patterns, and affect timing and duration of runoff.

8.2.10.1 Research Literature Base

The research literature on the effects of ice/snowpack on performance is very limited, apart from a fairly good understanding of slipping, which is usually researched through non-ice/snow-related methods of reducing the surface coefficient of friction (e.g., water/oil on floor surfaces). Formal research into the friction effects of snow are also very limited and tend to specifically involve the slowed progress of soldiers through snow rather than performance by other classes of workers. The effects of glare and slipperiness of icy tools (e.g., ladders) are widely noted due to the frequency of their adverse effects in cold climates.

8.2.10.2 Mechanisms of Action

Figure 8.23 presents an overview of ice and snowpack, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which they affect human performance, the effects on human performance, and potential ways in which effects on exposed individuals can be mitigated. The primary mechanisms by which ice/snowpack affects human performance are as follows:

- *Low coefficient of friction*. The mechanism of most common effects of ice/snowpack is slipperiness. Most typically this is with regard to "conditions underfoot which may interfere with movement, by causing a foot slide that may result in injury or harmful loading of body tissues due to a sudden release of energy" (Grönqvist, Chang, et al., 2001). When ice/snow-covered surfaces are encountered, the chance of slipping, or the sliding of the foot on a surface due to a lower coefficient of friction than is required for safe traction

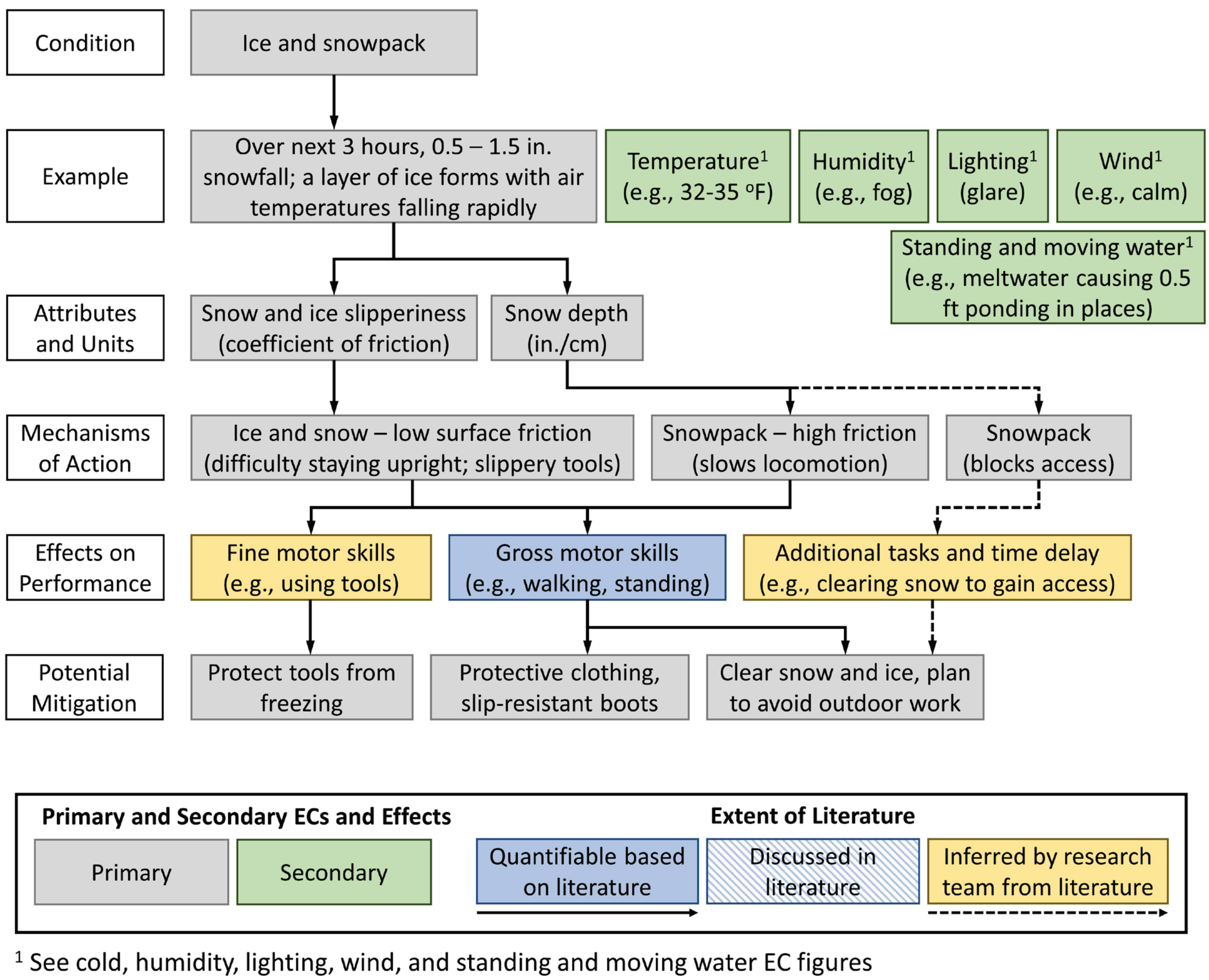


Figure 8.23 Ice and snowpack effects overview

increases significantly. Consequently, slippery surfaces slow gross motor performance at best, and often result in injuries. Low coefficient of friction can similarly impact fine motor performance when tools and interaction surfaces are coated with ice.

- *Drag.* Drag occurs because loose snow tends to result in increased friction between itself and a worker's feet and legs. This resistance worsens with snow depth, slowing walkers and requiring them to expend more energy to complete the same actions. Further, warm clothing and gloves can slow the workers progression and task completion rate.
- *Reduced attentional resources.* Perception of risk for falling (as with standing and moving water), glare from reflected light, as well as added challenges of fine and gross motor activities can individually and altogether serve to reduce attentional resources.
- *Secondary mechanisms.* Other EC effects often co-occur with ice and snow; thus, their associated mechanisms of action come into play when ice/snowpack is encountered as well. For example, both snow and ice can reflect a great deal of light, producing significant glare (impacting visual tasks, as well as fine and gross motor activities) and possible snow blindness (both requiring medical intervention and affecting any work performance). Further, when large amounts of snow melt, standing and/or moving water is often encountered (sometimes with a hazardous overlay of snow and ice) (for details, see Volume II, Chapter 6, Light and Chapter 10, Standing and Moving Water).

8.2.10.3 Broad Effects on Performance

Research has shown that ice/snowpack affects human performance in the following ways:

- *Broad motor skill slowing.* Snow depth shows a fairly linear slowing effect on walking speed (Figure 8.24, Volume II, Figure 11.3 (Ramaswamy et al., 1966)). Progress through snow also tires walkers more quickly because of the increased energy expenditure requirements. Failure to maintain adequate grip on ice-covered tools can similarly slow tool-handling interactions. The presence of protective clothing, such as heavy jackets and gloves can delay both gross and fine motor actions.
- *Slip/fall injuries.* The primary effects of ice and snowpack on performance are on gross motor performance. Falls caused by slipping and tripping while walking constitute the majority of industrial accidents and are the cause of up to 15 percent of accidental deaths. Carrying or even holding a load while walking exacerbates the risk, because doing so interferes with postural stability.

The relative impacts ice and snowpack have on individual performance demands may be assigned for a nominal flooding event task as illustrated in Table 8.22. The nominal flood event task, arbitrarily chosen solely for illustrative purposes, involves carrying and setting up flood barriers around a critical operations building after a nighttime snowstorm, followed by environmental warming surpassing 60°F after daybreak with bright sunlight glare impeding reading of setup instructions. The most significant effects on performance are on gross motor skills—namely walking on a slippery ice surface or through a snowpack of significant depth. To the extent that other activities involve travel in these conditions (e.g., cooperation), they may be affected as well.

Table 8.22 Summary of ice and snowpack on performance and relative impact of environmental conditions by performance demands[(a)]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Ice/Snowpack on Performance	Impact of Ice/Snowpack on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	-	High
Sensation and visual recognition	-	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	-	Med
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	-	Med
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Motor Slowing	Med
Gross motor skills – heavy and light	Motor Slowing; Slip/Fall Injuries	Med/High
Other neurophysiological functions	Slip/Fall Injuries	Low
Teamwork		
Reading and writing	-	High
In-person and electronic oral communication	-	Low
Cooperation, crew interaction, and command and control	Slip/Fall Injuries	Med

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, involves carrying and setting up flood barriers around a critical operations building after a nighttime snowstorm, followed by environmental warming surpassing 60°F after daybreak with bright sunlight glare impeding reading of setup instructions.

8.2.10.4 Summary of Research Literature Review Results

A detailed literature review of ice and snowpack is presented in Volume II, Chapter 11. A plot related to this summary is in the following section. Insights from that review include the following:

- Quantitative measures
  - The **impairing effects of snow friction on walking progress** can be predicted with some reliability **based on snow depth** as in Figure 8.24 (see Volume II, Figure 11-3 (adapted from Ramaswamy et al., 1966)). A regression of this data yields a regression equation (8-4).
- Thresholds, measures for success
  - The probability of slipping can be modeled reasonably well if the interaction between the coefficient of friction of the ice/snow and of footwear is known. However, it is unlikely to be practical to obtain these measures under most NPP situations

requiring manual actions. The **minimum coefficient of friction for safe walking is 0.2** on a flat surface (see Volume II, Section 11.4.1 (Shintani et al., 2003)).

- Snow depth **greater than 3 in** is considered to cause **moderate degradation**[3] for engineering personnel movements, while depth **greater than 6 in** cause **severe degradation** in engineering personnel movements (U.S. Army, 1992).
- Snowfall at **1-3 in/hour causes moderate degradation** in personnel movement while heavy snowfall at rates **greater than 3 in/hour causes severe degradation** in personnel movement (U.S. Army, 1992).
- Models of **load carrying walking speeds** assign a **factor of 1.7 for hard snow** vs. 1.0 for dry pavement (Richmond et al., 2015).

* Qualitative measures
    - Interestingly, workers' subjective awareness of potential slipperiness can increase the likelihood of slipping, because people tend to take defensive actions (e.g., shortening strides, slowing walking speed, and stepping flatter footed), which further reduces the forces at work that might otherwise overcome slippage (see Volume II, Section 11.4.1).

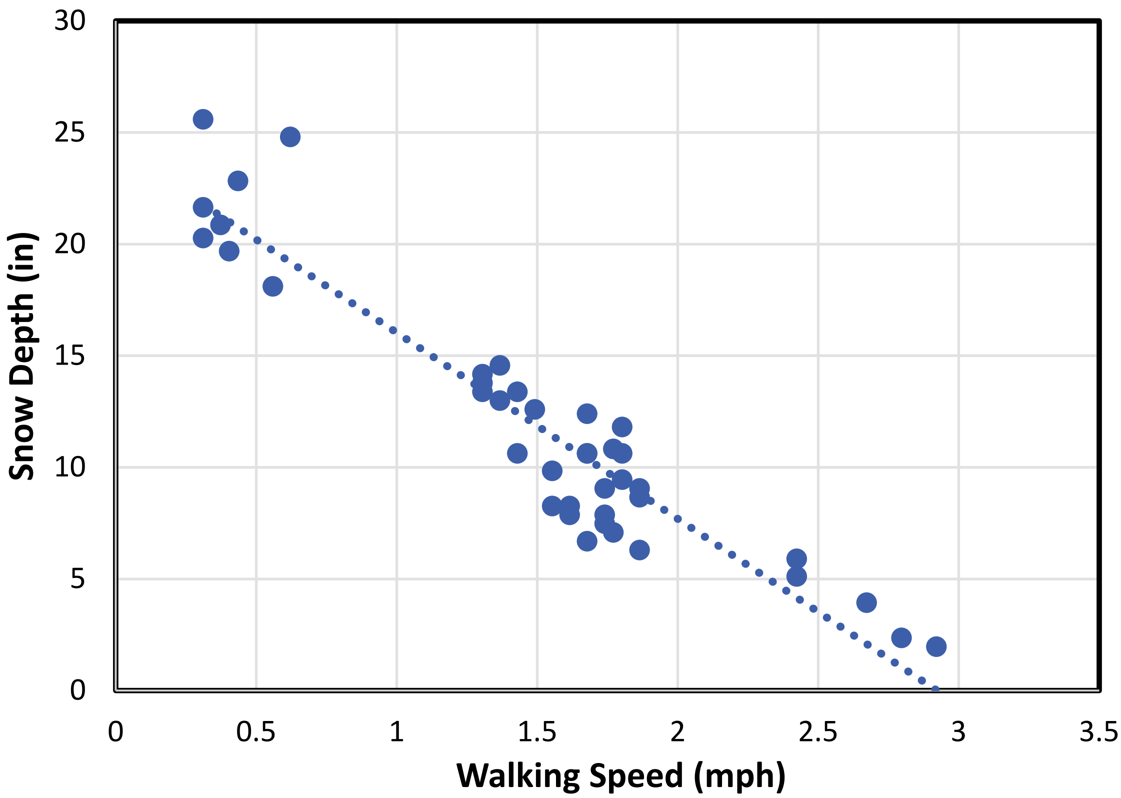


Figure 8.24 Impact of snow depth on walking speed (Adapted from Ramaswamy et al., 1966)

[3] U.S Army Field Manual defines moderate performance impact as normal effectiveness reduced 25-75% and severe impact as normal effective reduce to 0-25%

8.2.10.5 Quantitative Equation and Plot

This section details an equation and a plot identified in the summary of research literature review results.

The following equation can be used to estimate the effects of snow depth on walking speed (as well as relative manual handling task speeds):

$$V_w = -\left(\frac{10\left((1000 * d_s) - 24371\right)}{83389}\right) \tag{8-4}$$

where V_w is walking speed (mph) and ds is snow depth (in.).

8.2.11 Lightning

Lightning is a rapid discharge of electricity within a cloud, or between a cloud and the ground. It is characterized by a bright flash of light and is typically accompanied by thunder. About 90 percent of lightning that strikes the ground is a negatively charged “leader” developing downward from a cloud and forming a connection with positively charged air above taller objects on the ground. Lightning is measured in electric current (amps) and electrical potential (volts). According to the National Weather Service, the typical lightning flash is about 300 million volts with about 30,000 amps. Lightning is a very dangerous EC with risks of a direct strike (often fatal), explosive destruction of trees and other objects, fire, as well as ground current, and electricity conduction by heavy equipment or other metal objects. Lightning can render electronic communication equipment inoperable; and corded telephones and computers conduct electricity, making them dangerous for personnel to use during a lightning storm. Individuals working outdoors are at increased risk if they work in open spaces, on or near tall objects, or with conductive materials and/or explosives. This is especially true of workers working with combinations of these risk factors, e.g., power utility field repair personnel. Operating procedures at an NPP often preclude working outdoors during a thunderstorm because they likely follow conservative safety recommendations. Nonetheless, personnel performing MAs in advance of a storm may have some risk of exposure both because (1) they may be caught outside as lightning begins and (2) the threat of lightning strikes exists even when storms are 10 to 15 mi away and skies are clear.

8.2.11.1 Research Literature Base

The research literature on lightning has been exclusively focused on safety (human and equipment). Specific work beyond safety has probably not been directly pursued because of the dangers inherent in such research. A detailed review of the research literature on lightning is provided in Volume II, Chapter 12.

8.2.11.2 Mechanisms of Action

Figure 8.25 presents an overview of lightning, including its attributes, units of measurement, likely co-occurring ECs, mechanisms of action through which it affects human performance, the effects on human performance, and potential ways in which its effects on exposed individuals can be mitigated. The primary mechanisms by which lightning affects human performance are as follows:

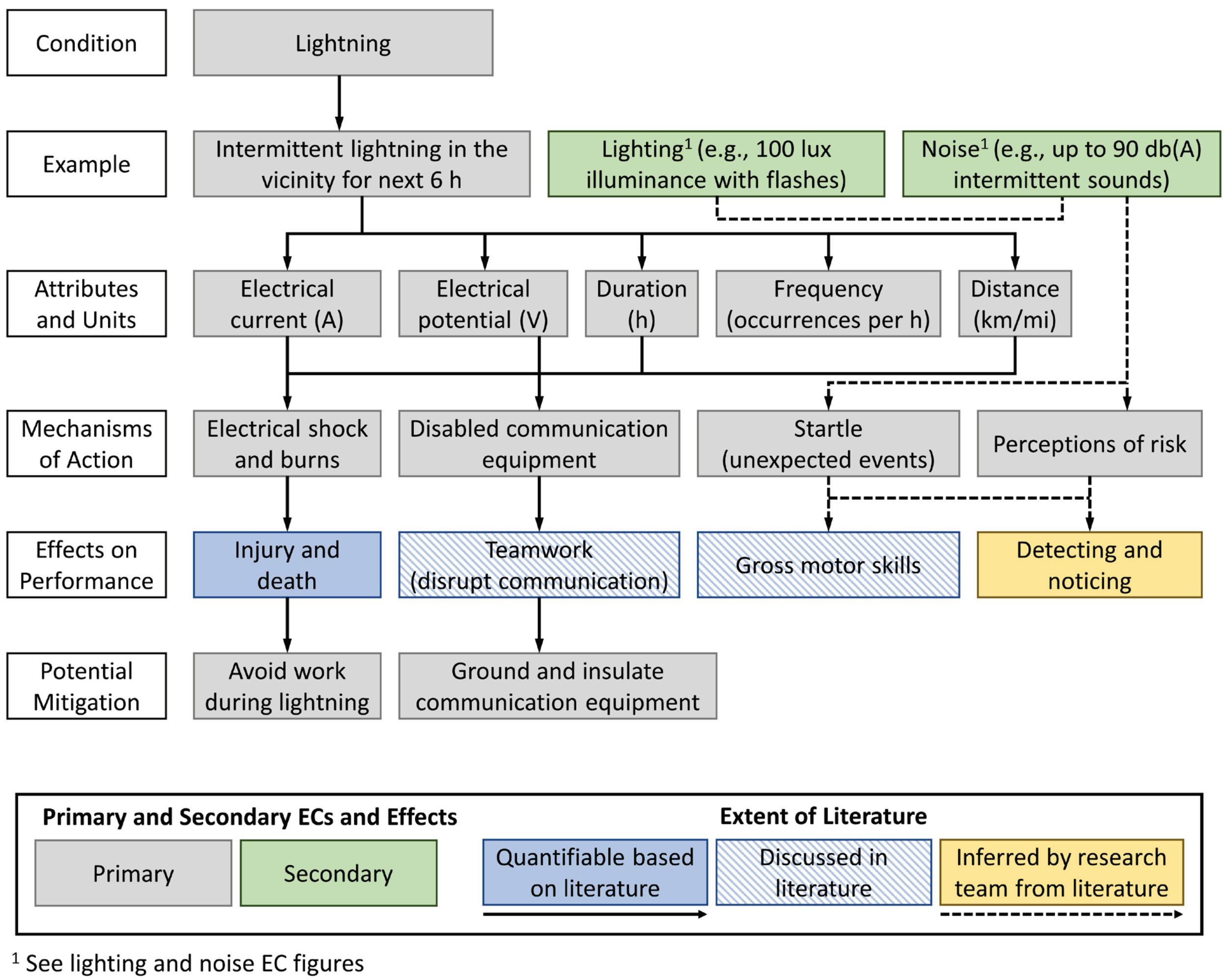


Figure 8.25 Lightning effects overview

- *Electricity/heat injury.* The primary mechanism relevant to safety concerns is the profound electrical and heat exposures that can occur when individuals are exposed directly or indirectly (ground currents) to lightning.
- *Directly disrupted auditory and visual performances.* The loud sounds and bright flashes of light can disrupt concurrent auditory and visual detection, recognition, and communication task performance. These effects can persist while those subjected to the sound and flash recover from associated aftereffects (see Volume II, Chapters 4, Noise and 6, Lighting).
- *Startle/stress response.* The startle effect from loud, unpredictable noise and brilliant light flashes (see Volume II, Chapters 4, Noise and 6, Lighting) suggest their occurrence following sudden lightning and thunder is likely to disrupt ongoing cognition and/or behavior completely for some brief period of time. Auditory and visual abilities would be impacted until overloaded receptors recover. In addition, startle may engender stress-related reticular activating system release of cortisol, epinephrine, and norepinephrine into the bloodstream, as well as the well-researched effects on cognition from disruptive pulses of sound and light.

8.2.11.3 Broad Effects on Performance

Research has shown that lightning affects human performance in the following ways:

- *Auditory and visual detection and recognition.* Auditory and visual detection and recognition abilities are impaired either by masking during thunder and lightning or during sensory recovery following sensory overloads (i.e., as aftereffects).
- *Motor and cognitive effects.* Thunder and lightning are likely to completely disrupt most physical and cognitive activities due to the startle response. Subsequent reticular activating system stress responses are also likely to prolong/compound these effects, potentially causing cascades of attention, basic cognition and reasoning, as well as fine and gross motor issues and mistakes.

The relative impacts that lightning has on individual performance demands (assuming no morbidity or mortality due to injury) may be assigned for a nominal flooding event task as illustrated in Table 8.23. The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, assumes that two workers have been sent outside during a thunderstorm to determine whether immediate fire risk exists after a transformer lightning strike.

Assuming ongoing lightning strikes are occurring, both the sensory disruption and/or startle effects may directly disrupt ongoing physical, perceptual, attention, and higher cognition activities. Such effects may continue after the lightning strikes for some time, while workers are recovering from the auditory and visual sensory aftereffects and/or those accompanying activation of the reticular activating system. Lightning can also directly (via knockouts) and indirectly (via worker avoidance of potential shock risks) disrupt electronic communications and therefore team activities that require them as well.

8.2.11.4 Summary of Research Literature Review Results

A detailed literature review of lightning is presented in Volume II, Chapter 12. Insights from that review include the following:

- Quantitative measures
  - Quantitative measures for lightning's effect on performance do not directly exist, due to the inherent hazards involved for participants in such research (see Volume II, Chapter 12 Lightning).
- Thresholds, measures for success
  - There is no safe level of lightning. Personnel should move to safe spaces at the first detection of lightning and then remain sheltered until the all-clear from a lightning storm is announced. Outdoor activities arguably should not be resumed until 30 minutes after the storm has passed (see Volume II, Chapter 12 Lightning). This 30-minute delay may be useful in estimating timed delay for a task under lightning conditions.
- Qualitative measures
  - Qualitative measures for lightning's effect on performance do not exist, due to the inherent hazards involved for participants in such research.

Table 8.23 Summary of lightning effects on performance and relative impact of environmental conditions by performance demands[(a)]. Illustrative variations based on authors' review of literature for a nominal flooding event task.

Performance Demands	Effects of Lightning on Performance	Impact of Lightning on Performance Demands
Detecting and Noticing		
Attention, memory, vigilance, switching, acuity, perception and threshold perception	Loud Noise and Bright light flashes; Startle/Stress Response	High
Sensation and visual recognition	Loud Noise and Bright light flashes; Startle/Stress Response	High
Understanding		
Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating	Loud Noise and Bright light flashes; Startle/Stress Response	High
Decision-making		
Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options	Loud Noise and Bright light flashes; Startle/Stress Response	High
Action		
Fine motor skills – discrete and motor continuous, and manual dexterity	Loud Noise and Bright light flashes; Startle/Stress Response	High
Gross motor skills – heavy and light	Loud Noise and Bright light flashes; Startle/Stress Response	High
Other neurophysiological functions	Startle/Stress Response (neuro-imagery, and –chemical)	High
Teamwork		
Reading and writing	Loud Noise and Bright light flashes; Startle/Stress Response	High
In-person and electronic oral communication	Loud Noise and Bright light flashes; Equipment shock risks; Startle/Stress Response	High
Cooperation, crew interaction, and command and control	Communication interference; Startle/Stress Response	High

(a) The nominal flooding event task, arbitrarily chosen solely for illustrative purposes, assumes that two workers have been sent outside during local thunderstorm activity to determine whether immediate fire risk exists after a transformer lightning strike.

8.3 Variation in Environmental Conditions

Flood parameters[4] vary over the duration[5] of a flooding event. Environmental Conditions associated with a flood can also vary over the duration of a flooding event. The variation of ECs

[4] From Prasad and Meyer (2016): Flood parameters are characteristics of the flood flow. Examples of flood parameters are flood discharge, flood velocity, floodwater-surface elevation or flood height, flood depth, flood event duration, hydrostatic and hydrodynamic forces, sediment concentration, debris composition, and inundation area.

[5] The duration of a flood event is defined as "[t]he length of time in which the flood event affects the site, beginning with notification of an impending flood (e.g., a flood forecast or notification of dam failure), including preparation for

in time depends on which FCM or combination of FCMs generates the flooding event, the timing of the flooding event (day or night, season), the duration of the flooding event (hours to days to weeks), and the prevailing weather near the nuclear power plant during the duration of the flooding event. As an example, Figure 8.26 is a plot of several meteorological variables (hourly precipitation, hourly average air temperature and dewpoint, hourly average wind speed and hourly wind gusts) concurrent with an approximately 2-month high discharge period on the Schuylkill River near Pottstown, Pennsylvania. The daily discharge in the Schuylkill River was obtained from a U.S. Geological Survey streamflow gauge (USGS, 2018). The hourly meteorological data were obtained from the Pennsylvania State Climatologist's office for a station located approximately 8 mi from the USGS streamflow gauge. It should be noted that the flood discharge in the Schuylkill River at this location results from runoff generated by precipitation in the approximately 1,150 mi^2 upstream drainage area and therefore the meteorological variables' plots with time are related to, but may not be an accurate reflection of, the meteorological conditions in the upstream drainage area.

The diurnal variation in air temperature is evident in the third panel of Figure 8.26, as is the gradual decrease in daily air temperatures as late spring advances into early fall. Three distinct flood peaks are present during this period. The flooding event associated with the second of the three flood peaks lasted approximately 16 days (from September 4 to September 19, 2011) and is shown in detail in Figure 8.27. The hourly average air temperature during this flooding event varied from a high of approximately 84°F (on September 4, 2011) to a low of approximately 44°F (on September 16, 2011). The time for the flood to rise to its peak was approximately 5 days and to recede from the peak was approximately 14 days. During the time that the flood discharge in the Schuylkill River was rising to the peak (September 4 to 9, 2011), precipitation was occurring near the streamflow gauge (Figure 8.27). During the same time, hourly average air temperatures dropped from a high of approximately 84°F on September 4 to a low of approximately 60.5°F on September 6, followed by a warming to 81°F on September 9 just as the flood reached its peak (Figure 8.27). Hourly average wind speeds varied from calm to over 10 mph with gusts reaching almost 30 mph on September 5. Therefore, any MAs that required outdoor work before the flood reached its peak, would have exposed workers to varying precipitation intensity, wind speeds, and temperatures, including periods of relatively low temperatures.

Flood parameters also vary in space. Spatial variation can occur at a range of scales, from the watershed or drainage basin where flooding occurs to the local, NPP site scale. For flood protection and mitigation procedures carried out at and near the NPP site, local-scale spatial variation of flood parameters is of particular interest. These spatial variations result from (1) the dynamics of floodwater flow, (2) the terrain (e.g., depth of floodwaters can be different in two locations with same floodwater surface elevation but different topographic elevations), and (3)

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the flood and the period of inundation, and ending when water has receded from the site and the plant has reached a stable state that can be maintained indefinitely" (JLD-ISG-2012-05, USNRC, 2012b).

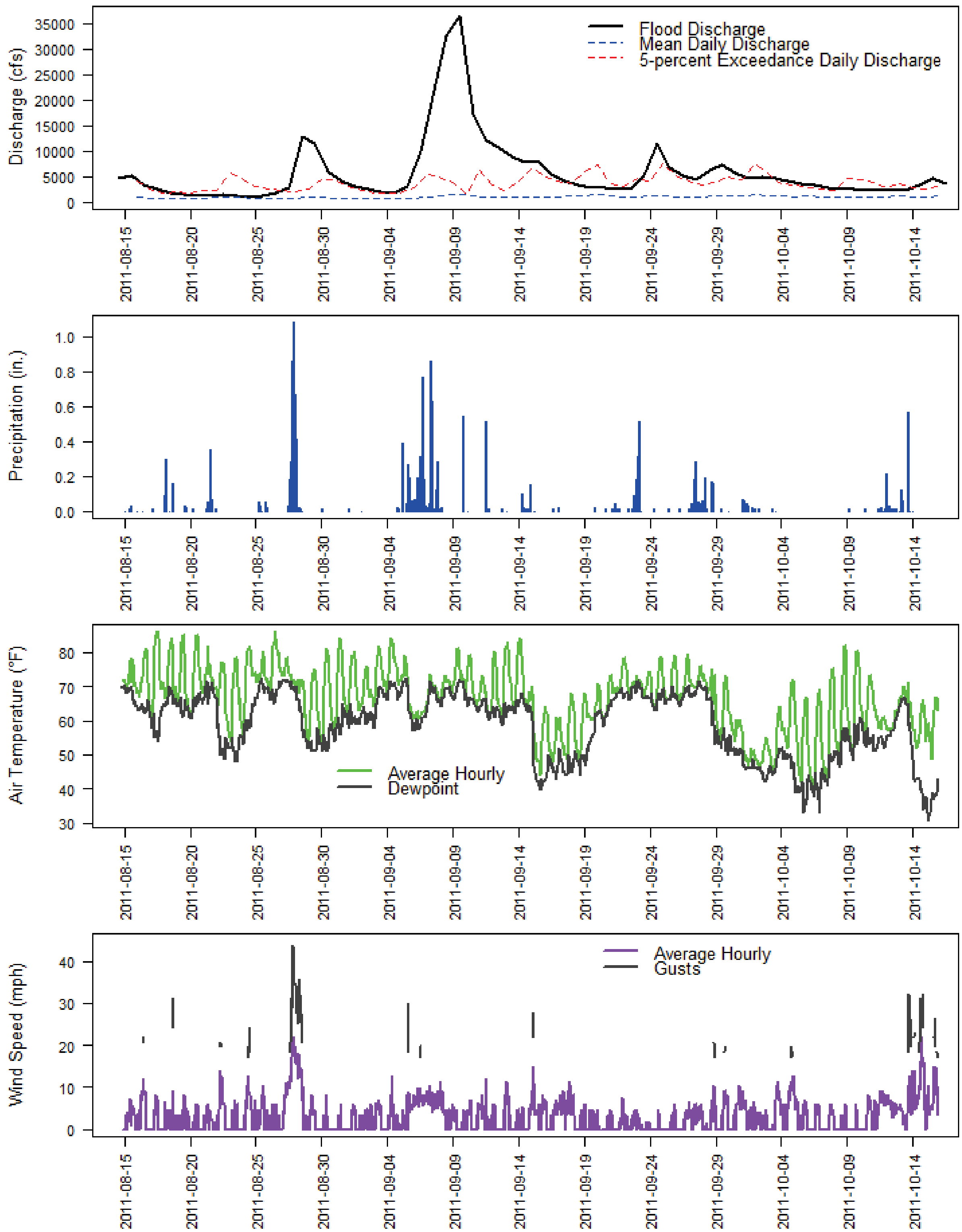


Figure 8.26 Hydro-meteorological variables concurrent with a high discharge period; August 15 to October 14, 2011; Schuylkill River near Pottstown, Pennsylvania

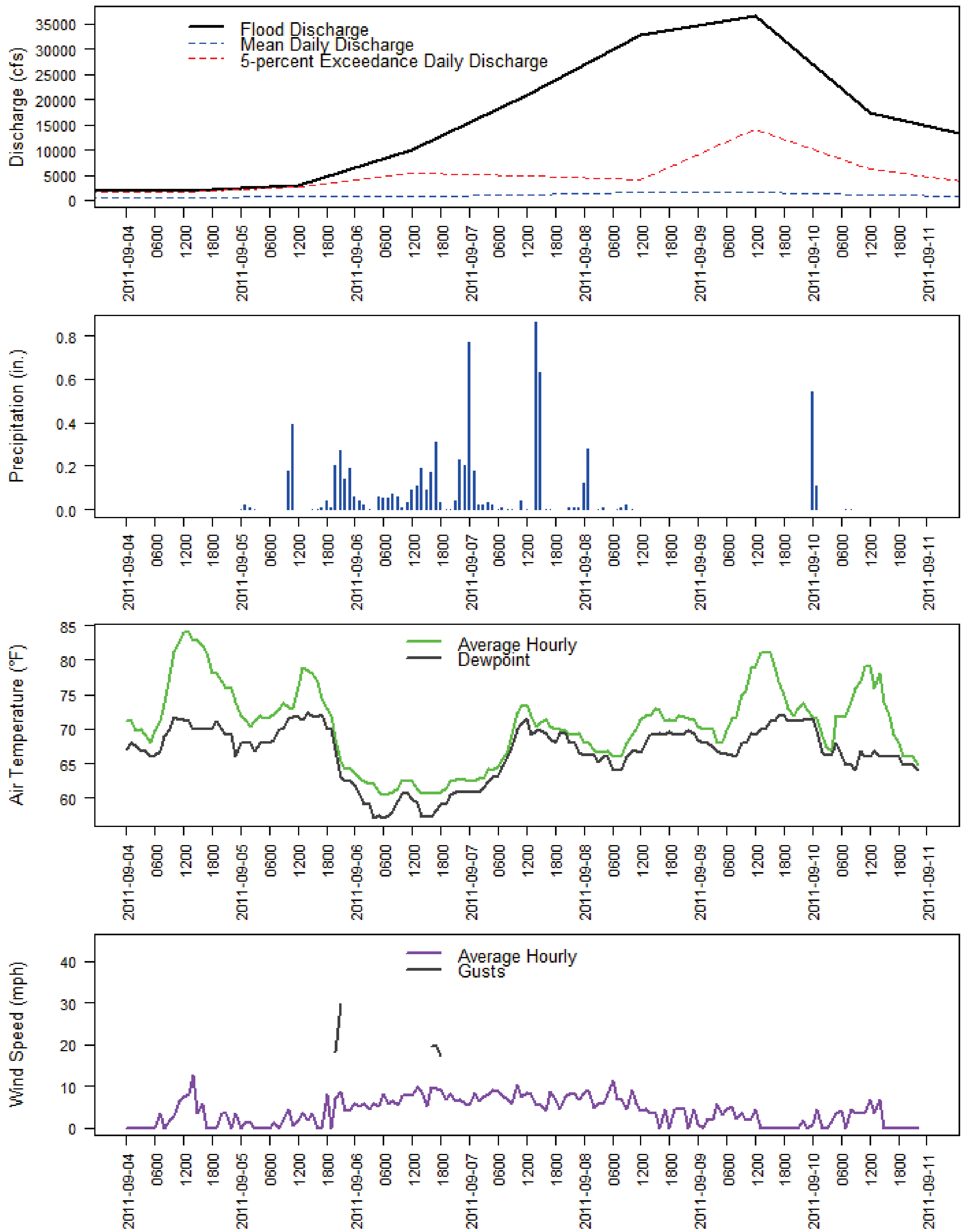


Figure 8.27 Hydro-meteorological variables plotted concurrent with the rise of a flood; September 4 to 11, 2011 Schuylkill River near Pottstown, Pennsylvania

the layout of obstructions (e.g., floodwater flow dynamics between and around buildings). Therefore, flood parameters of interest to flood protection and mitigation procedures have spatiotemporal variation that should be considered when planning and executing these procedures. The spatiotemporal variation of flood parameters can be represented by dynamic maps. Environmental conditions that are, or are directly related to, the flood parameters (e.g., floodwater depth and velocity, drag forces) can also be represented by similar dynamic maps. Other environmental conditions of interest may not vary significantly at the outdoor locations on an NPP site (e.g., air temperature, humidity). In addition, environmental conditions can vary between indoor and outdoor locations (e.g., air temperature, lighting) and because of sheltering (e.g., precipitation or wind effects under unsheltered and sheltered locations). Manifestation of secondary ECs would also be affected by local and equipment-specific conditions (e.g., surface properties of walkway, tool material, and gauge design).

9 ILLUSTRATIVE APPLICATION OF THE ENVIRONMENTAL CONDITION IMPACT ASSESSMENT APPROACH

This chapter demonstrates an example application of the research team's approach to assessment of impacts of environmental conditions (ECs) on manual actions (MAs). This proof-of-concept approach quantifies the impact of how ECs affect human performance by affecting performance demands. The quantitative approach is illustrated by applying it to one subtask of a manual action assumed to be affected by a single EC – heavy rain. This chapter describes an example method of how the results of the human performance research literature review can be used. Limitations and caveats of this preliminary quantitative approach are also described.

9.1 Proof-of-Concept Method for Environmental Condition Impact Assessment

A fundamental element of the proof-of-concept approach described here is the identification and use of the performance demands required by the site-specific specific actions (SAs). Section 5.2.4 earlier described a task performance taxonomy (Coles et al., 2017) compiled from three sources into a single superset. This superset was used by the research team to both (1) relate impacts from ECs to performance demands required by SAs, and (2) organize the review of the research literature about the impacts of ECs on task performance. The resulting compiled performance demand taxonomy is as follows:

1. Detecting and noticing
    a. Attention, memory, vigilance, switching, acuity, perception, and threshold perception
    b. Sensation and visual recognition
2. Understanding
    a. Pattern recognition, discrimination, evaluating, hypothesizing, diagnosing, and integrating
3. Decision-making
    a. Reasoning, computation, interpreting, classifying, goal setting, planning, adapting, and evaluating and selecting options
4. Action
    a. Fine motor skills – discrete and motor continuous, and manual dexterity
    b. Gross motor skills – heavy and light
    c. Other neurophysiological functions
5. Teamwork
    a. Reading and writing
    b. In-person and electronic oral communication
6. Cooperation
    a. Crew interaction, and command and control.

Building upon the approach discussed in the previous chapters for defining performance demands, the research team delineates a proof-of-concept method for assessing the impact of ECs on flood protection and mitigation MA performance. As discussed in Chapter 6, MAs may be decomposed into multiple tasks, subtasks, and SAs. By estimating the impact of prevailing ECs on each SA, and aggregating these impacts, analysts can derive an estimate of the ECs' impact on the subtasks, tasks, and the MA comprised of these SAs. One way to operationalize the impact of ECs is in terms of the time it takes for an individual to perform an MA given a specific set of prevailing ECs. Likewise, the impacts of ECs can also be operationalized in terms of the increase in error rates during performance of the MA. The research team's proof-of-concept method using the impacts of ECs on time is illustrated in Figure 9.1.

As Chapter 5 illustrated, to estimate the impact of ECs on SAs and provide a basis for aggregating impacts to the MA level, a necessary step is to evaluate and quantify the performance demands associated with each SA. This can be accomplished using the consolidated taxonomy developed in Section 5.2.4. As shown in Figure 9.1, the impact assessment at a given nuclear power plant (NPP) site starts with the decomposition of one of the site's MAs into its constituent SAs. The result is a compilation of site-specific SAs that form the subtasks, tasks, and the MAs. The assessment also requires (1) the performance demand profile of each SA (depicted by the color wheel in the middle-top of Figure 9.1), (2) the severity of the prevailing EC[1], (3) the impact factor[2] for each performance demand from the prevailing EC, and (4) the baseline time for performing each SA.

Alternatively, if the generalized action framework (as discussed in Ch 7.1.1) is used, the first step of the process is the re-composition of one of the site's MAs by combining pertinent site-independent GAs with site-specific task context (Figure 9.2). The following steps are the same as for the basic framework.

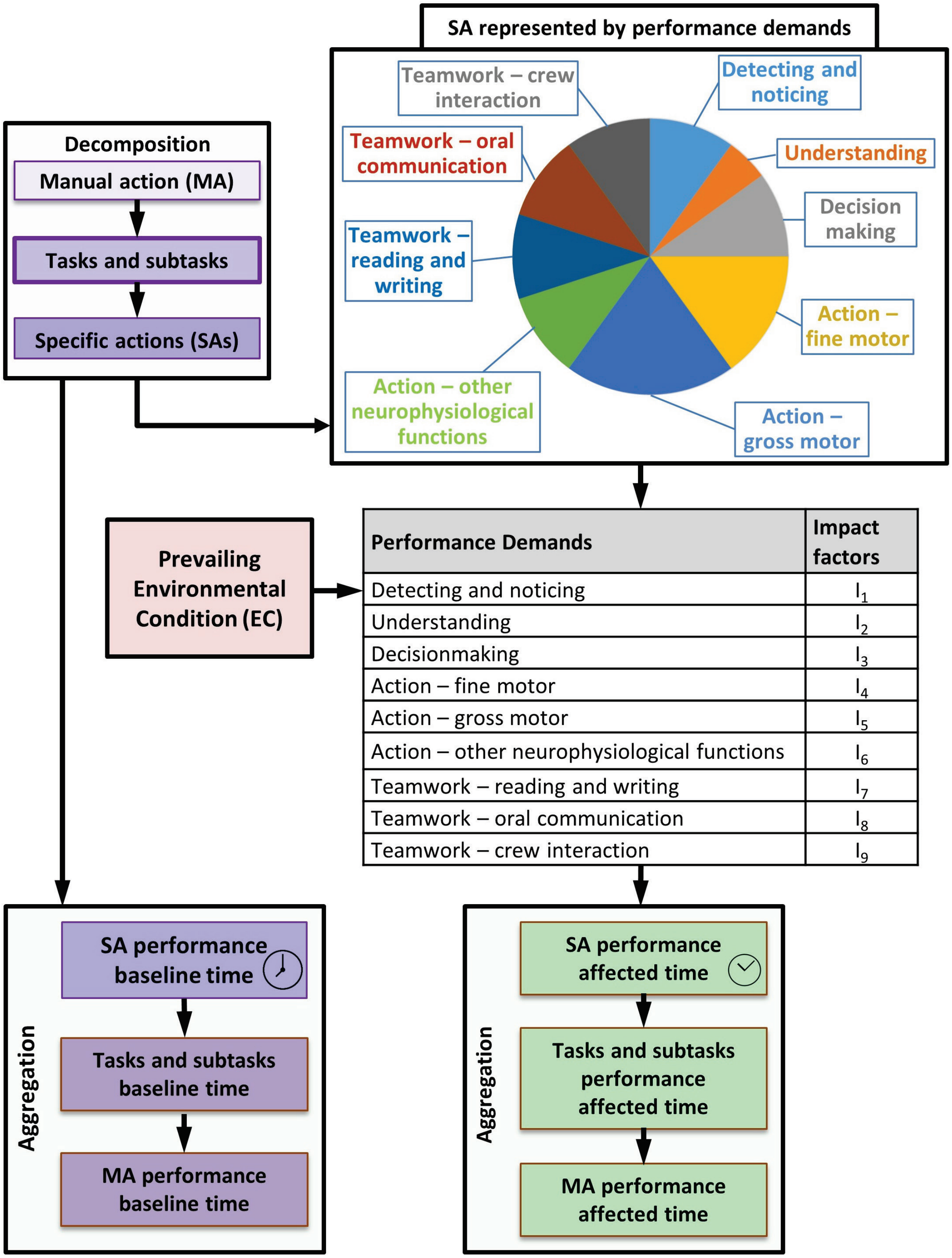
Performing different SAs, such as operating a vehicle to transport equipment from a designated location to a target location or setting up a sump pump in a designated building, requires an individual to meet the requirements associated with a mixture of cognitive (e.g., attention and memory that consume mental energy) and non-cognitive demands (e.g., gross and fine motor movements that consume physical energy). The performance demands vary by SA. Here the research team provides a preliminary discussion of the initial conceptualization of a proportional approach that might serve this purpose, while acknowledging that additional technical details remain to be developed (e.g., the dimensions and scale needed for working out the remaining details of this approach).

Using the proposed proportional approach, SAs would be characterized in terms of the combination of performance demands that must be met for their completion. This concept can be illustrated by comparing the contributors for two different SAs using pie charts as shown in Figure 9.3. In this example, one of the SAs associated with an MA -- "build a sandbag berm around the service water strainer pit" (see Section 6.3.3) – involves taking sandbags off the fill rack. This SA predominantly requires gross motor skills, some fine motor skills, and has a low level of cognitive performance demand. By contrast, another SA—operate a powered hoist to load a pump on a transport vehicle—relies more heavily on detecting and noticing, as well as fine motor skills, and less on gross motor skills.[3] Such information provides a basis for weighting the impact of an EC on performance demands commensurate with their relative importance to successful completion of the SA.

[1] In general, multiple ECs, including secondary ECs may prevail. In this illustrative example, for simplicity, only one EC prevails.

[2] Impact factor is defined later in this section to refer to a numerical measure of the increase I time to perform an SA, or the increase in error rate for performing an SA, or the increase in the probability of failing to perform an SA.

[3] "Operating a powered hoist" was part of an MA—install a portable pump (see Section 6.3.1).



Performance Demands	Impact factors
Detecting and noticing	I_1
Understanding	I_2
Decisionmaking	I_3
Action – fine motor	I_4
Action – gross motor	I_5
Action – other neurophysiological functions	I_6
Teamwork – reading and writing	I_7
Teamwork – oral communication	I_8
Teamwork – crew interaction	I_9

Figure 9.1 Impact assessment of an environmental condition on decomposition of a manual action

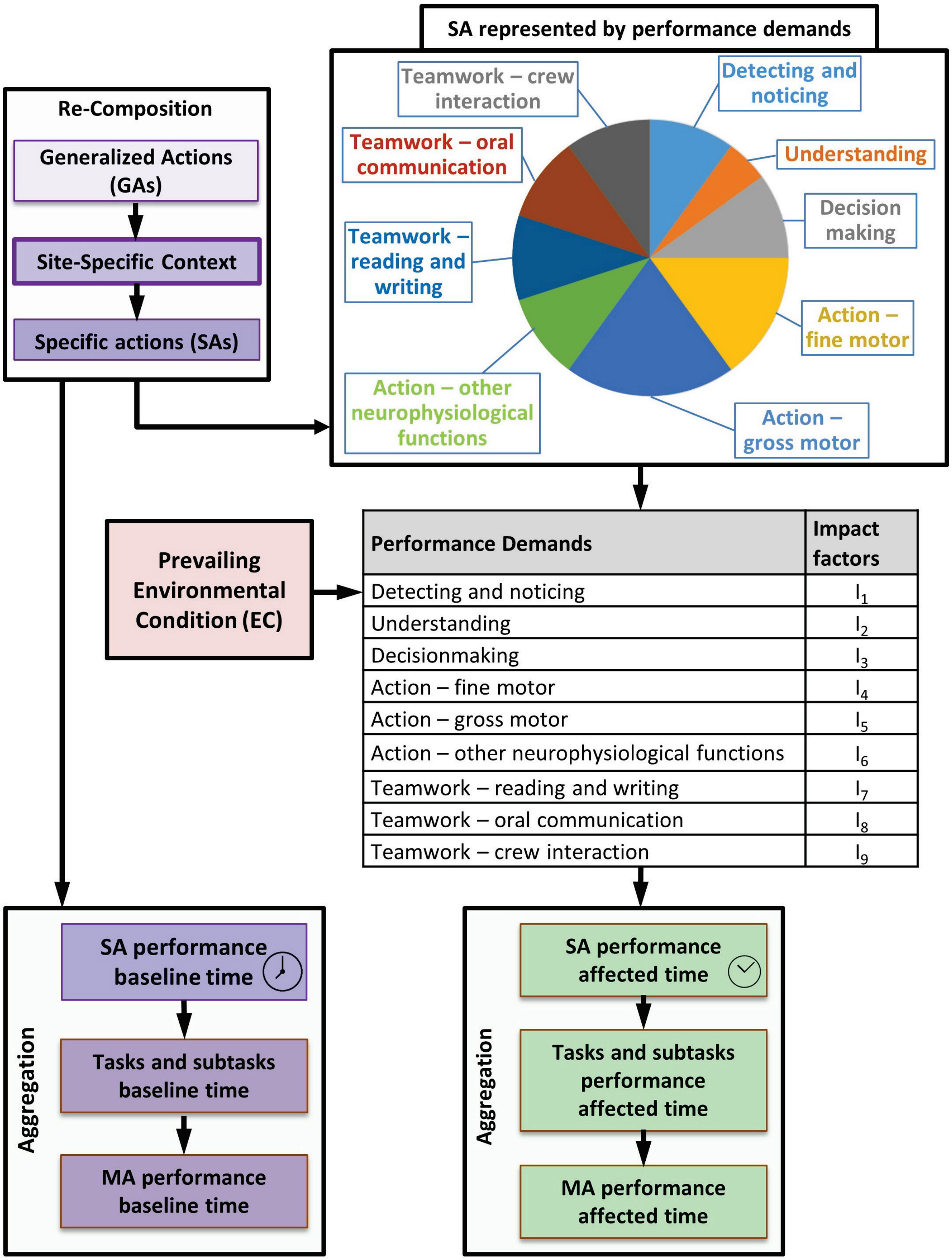


Figure 9.2 Impact assessment of an environmental condition on re-composition of generalized action

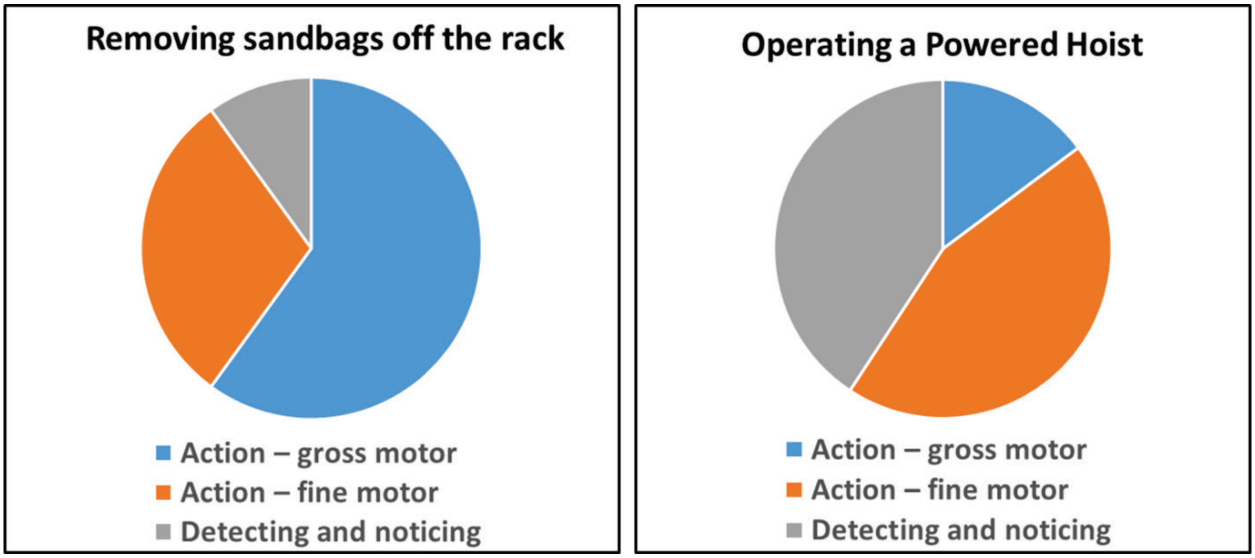


Figure 9.3 Nominal illustration of specific actions with different performance demand profiles

As indicated earlier, the proof-of-concept method developed by the research team and illustrated here focuses on the time required to complete a task as the primary measure of performance. This focus was motivated by the protracted time over which many flood protection and mitigation actions usually take place and the many opportunities to detect and correct or recover from most errors[4]. When an EC has adverse effects on workers, it is likely that the task performance time will be extended. The impact of ECs on the performance can thus be expressed as the baseline time plus additional time required to complete a task.

The approach for aggregating impact must account for the relative importance of each SA to the subtask, task, and MA. This may be accomplished by developing an approach for weighting the SAs in terms of their relative contribution to the performance of the subtask, task, and MA. A given EC may impact multiple performance demands, but also several ECs may impact a single performance demand.

The approach for aggregating impact must account for the relative importance of each SA to the subtask, task, and MA. This may be accomplished by developing an approach for weighting the SAs in terms of their relative contribution to the performance of the subtask, task, and MA. A given EC may impact multiple performance demands, but also several ECs may impact a single performance demand. To that end, at the SA level, let w_i be the weight for each performance demand *i*, where *i* =1, 2, 3,…9 (see Table 9.1); $w_i \in [0,1]$ and $\sum_{i=1}^{9} w_i = 1$. These weights correspond to the relative contributions of performance demands to the SA illustrated in Figure 9.3.

The research team defined the impact factor as a numerical measure of the increase in time to perform an SA, or the increase in error rate for performing an SA, or the increase in the probability of failing to perform an SA. Following the relative contribution of various performance demands to an SA Figure 9.3), the research team proposed that impact factors apply to portions

[4] Nonetheless, the same approach could be applied to other measures of human performance in future developments of the approach.

of an SA that require a particular performance demand. For an EC, let $I_{i,j}$ be the impact factor associated with E_j for each performance demand *i* (see Table 9.2) that contributes to performance of the SA. ECs of interest are described in Chapter 8.

Because it is assumed that an EC might impact various performance demands differently, the value of the impact factor associated with an EC is likely to be different for different performance demands. It is also assumed that $I_{i,j}$ is equal to or greater than 1 (i.e., generally adverse impacts of ECs are of interest). When $I_{i,j}$ is equal to 1, the EC is perceived to have no adverse impact. When $I_{i,j}$ is greater than 1, the EC would have an adverse impact on performance. In the following discussion, performance time is used as the measure of performance, therefore a performance time exceeding the available time for the MA would indicate failure[5]

Table 9.1 List of performance demands

Index	Performance Demands
i = 1	1 = Detecting and Noticing
i = 2	2 = Understanding
i = 3	3 = Decision-making
	4 = Action
i = 4	4.1 = Fine Motor
i = 5	4.2 = Gross Motor
i = 6	4.3 = Other Neurophysiological Functions
	5 = Teamwork
i = 7	5.1 = Reading and Writing
i = 8	5.2 = Oral Communication
i = 9	5.3 = Crew Interaction

Table 9.2 Environmental conditions impact factors associated with performance demands

Performance Demands (i)	Impact Factor ($I_{i,j}$) for EC (E_j)
1. Detecting and Noticing	$I_{1,j}$
2. Understanding	$I_{2,j}$
3. Decision-making	$I_{3,j}$
4. Action – Fine Motor	$I_{4,j}$
5. Action – Gross Motor	$I_{5,j}$
6. Action – Other neurophysiological functions	$I_{6,j}$
7. Reading/Writing	$I_{7,j}$
8. Oral Communication	$I_{8,j}$
9. Crew Interaction	$I_{9,j}$

[5] Failure modes are not limited to performance time exceeding available time but are the focus of this example.

When an EC is present during performance of an SA and when $I_{i,j} > 1$ it is likely that E_j will adversely affect the performance time of the overlying MA. The total impact of EC E_j on the SA could be represented as a time adjustment appropriately weighted by the relative contributions of the performance demands to the SA. To capture this impact (measured in terms of performance time), let

S_k	=	an SA, where $k = 1,2,3, \dots n_S$ and n_S is the number of SAs in the MA.
i	=	a performance demand required by S_k, where i ranges from 1 to 9 for the performance demands in this framework. The number of performance demands assessed can be generalized as n_i, where $n_i = 9$ for this framework's set of performance demands. These weights correspond to the relative contributions of performance demands to the SA as illustrated in Figure 9.3 above.
w_i	=	weight for performance demand i, where $w_i \in [0,1]$ and $\sum_{i=1}^{n_i} w_i = 1$
E_j	=	an EC, where $j = 1,2,3, \dots n_E$ and n_e is the number of ECs
$I_{i,j,k}$	=	impact factor for performance demand i from prevailing E_j within S_k
$t(S_k)$	=	baseline time for performing S_k
$t_{i,k}$	=	baseline time associated with performance demand i within S_k (such that $t_{i,k} = w_i t(S_k)$)
$\Delta_{i,j,k}$	=	time adjustment for performance demand i from prevailing E_j within S_k ($\Delta_{i,j,k} = I_{i,j,k} - 1$)
$t^*(S_k)$	=	affected time for performing S_k
$t^*_{i,k}$	=	affected time associated with performance demand i within S_k
B_l	=	a task or subtask consisting of one or more SAs, where $l = 1,2,3, \dots n_B$ and n_B is the number of subtasks
$t(B_l)$	=	baseline time for performing B_l
$t^*(B_l)$	=	affected time for performing B_l
M_o	=	an MA consisting of one or more tasks, where o is a positive integer
$t(M_o)$	=	baseline time for performing M_o, and
$t^*(M_o)$	=	affected time for performing M_o.

The baseline time for $t(S_k)$ can be expressed as:

$$\boldsymbol{t(S_k) = \sum_{i=1}^{n_i} t^*_{i,k}} \tag{9-1}$$

and the affected time for $t^*(S_k)$ given only one prevailing EC E_j, can be expressed as:

$$\boldsymbol{t^*(S_k) = \sum_{i=1}^{n_i} t^*_{i,k} = \sum_{i=1}^{n_i} (1 + \Delta_{i,j,k}) t_{i,k}} \tag{9-2}$$

The impact of E_j on the SA S_k, as measured by time, is the difference between affected time $t^*(S_k)$ and baseline time $t(S_k)$.

To account for the observation that impact on a performance demand can occur from several ECs, three options for combining the impacts stemming from multiple ECs are provided below.

For a simple additive combination, where n_E is the number of prevailing ECs while performing the SA S_k, the combined impact factor on performance demand i can be expressed as:

$$\boldsymbol{I_{i,k}} = \sum_{j=1}^{n_E} \boldsymbol{I_{i,j,k}} \tag{9-3}$$

For multiplicative combination, where n_E is the number of prevailing ECs while performing the SA S_k, the combined impact factor on performance demand i can be expressed as:

$$\boldsymbol{I_{i,k}} = \prod_{j=1}^{n_E} \boldsymbol{I_{i,j,k}} \tag{9-4}$$

For a power function combination, where α_j, $j = 1,2,3, \ldots n_E$ are the different exponents for prevailing ECs' impacts while performing the SA S_k, the combined impact factor on performance demand *i* can be expressed as:

$$\boldsymbol{I_{i,k}} = \prod_{j=1}^{n_E} \left(\boldsymbol{I_{i,j,k}}\right)^{\alpha_j} \tag{9-5}$$

Selection of these methods of calculation has been reviewed by Xing et al (2015) which, with a limited sample set, suggests that the multiplicative combination over-predicts, and the additive combination is a better choice. Selection of a combination method should be reviewed by a team of experts and assessed based on current literature. One possible approach is to evaluate the impacts using both the multiplication additive method to obtain an understanding of the sensitivity of the results to this assumption.

The affected time for S_k, given multiple prevailing ECs and using the additive combination can be expressed as:

$$\boldsymbol{t}^*(\boldsymbol{S_k}) = \sum_{i=1}^{n_i} \boldsymbol{t}^*_{i,k} = \sum_{i=1}^{n_i} (\boldsymbol{1} + \boldsymbol{\Delta_{i,k}})\boldsymbol{t_{i,k}} = \sum_{i=1}^{n_i} \boldsymbol{I_{i,k} w_i t(S_k)} = \boldsymbol{I^*_k}\, \boldsymbol{t(S_k)} \tag{9-6}$$

where I^*_k is the impact factor for the *k*th SA, appropriately weighted by performance demand weights.

As mentioned earlier, a task or subtask B_l can consist of one or more SAs, (i.e., $B_l = \{S_k\}, k = 1,2,3 \ldots n_S$. The baseline time for a task B_l can be written as follows, assuming its constituent SAs are performed sequentially:

$$\boldsymbol{t(B_l)} = \sum_{k=1}^{n_G} \boldsymbol{t(S_k)} \tag{9-7}$$

Thus, the affected time $t^*(B_l)$ for performing B_l can be expressed as:

$$t^*(B_l) = \sum_{k=1}^{n_S} t^*(S_k) = \sum_{k=1}^{n_S}\sum_{i=1}^{n_i}(1 + \Delta_{i,k})\, t_{i,k} = \sum_{k=1}^{n_S}\sum_{i=1}^{n_i} I_{i,k}\, t_{i,k} = \sum_{k=1}^{n_S} I_k^*\, t(S_k) \tag{9-8}$$

The above expression applies when SAs constituting a task (or subtask) are performed sequentially such that impacts on different SAs result in an additive impact to the overlying task/subtask.

Because an MA M_o typically consists of one or more tasks (and subtasks), that is:

$$M_o = \{B_l\}, l = 1, 2, 3 \dots n_B$$

the baseline time $t(M_o)$ for performing an MA M_o can be expressed as follows, assuming the tasks are performed sequentially:

$$t(M_o) = \sum_{l=1}^{n_B} t(B_l) \tag{9-9}$$

and the affected time $t^*(M_o)$ for performing M_o is:

$$t^*(M_o) = \sum_{l=1}^{n_B} t^*(B_l) \tag{9-10}$$

The tasks encompassed in a flood protection and mitigation MA could be performed sequentially, in parallel, iteratively, or in other task orders with loops and interdependencies. Although these more complex task orders are not presented in this formulation, they can be modeled computationally using the terms defined above.

9.2 Example Application of the Proof-of-Concept Method

In this section, the proof-of-concept method outlined above is demonstrated through an example MA. The research team selected an MA that was risk significant, took place over an extended period of time and had exposure to some ECs (e.g., the action included elements that are performed outdoors and near flooding).

The selected example MA is "fastening barriers onto intake structure walls" based on an MA from a real life NPP flood protection and mitigation procedure, but for which many details were extrapolated because they were not known by the research team. This MA was decomposed into five tasks (shown below in Table 9.3). Task 5 was further decomposed into four subtasks, and each of the subtasks was decomposed into one or more SAs. The research team focuses on Task 5 to illustrate the method described in Section 6.3.3.

Note, in this example, the research team assumes some SAs and tasks can be performed concurrently. For example, Tasks 1 and 2 can be performed in parallel; Tasks 3 and 4 can also be performed in parallel but only after Tasks 1 and 2 are completed. The research team also assumes Task 5, and its constituent subtasks and SAs, must be executed sequentially. The dependently structured sequence for performing the example MA is shown in Figure 9.4.

Table 9.3 Example manual action: Fastening barriers onto intake structure walls

Example MA: Fastening Barriers onto Intake Structure Walls
Task 1. Fabricate steel plates
Task 2. Clear debris – could be done parallel to Task 1
Task 3. Stage plates and equipment – must be done sequential with Tasks1 and 2
Task 4. Prepare wall surface – could be parallel to Task 3
Task 5. Fasten 4 barriers
Subtask 5.1. Position forklift
SA 5.1.a Walking
SA 5.1.b Getting forklift.
SA 5.1.c Driving forklift.
Subtask 5.2. Load plates onto forklift.
SA 5.2.a Operating forklift (picking up).
Subtask 5.3. Position plates against structure wall with forklift.
SA 5.3.a Operate forklift (lifting the plate).
SA 5.3.b Communicate and coordinate.
SA 5.3.c Operate forklift (position the plate).
SA 5.3.d Manually adjust plate position against wall.
Subtask 5.4. Drill holes and secure with fasteners
SA 5.4.a Hand tools (drill)
Subtask 5.4. Drill holes and secure with fasteners
SA 5.4.a Hand tools (drill)
SA 5.4.b Hand tools (concrete bolts)

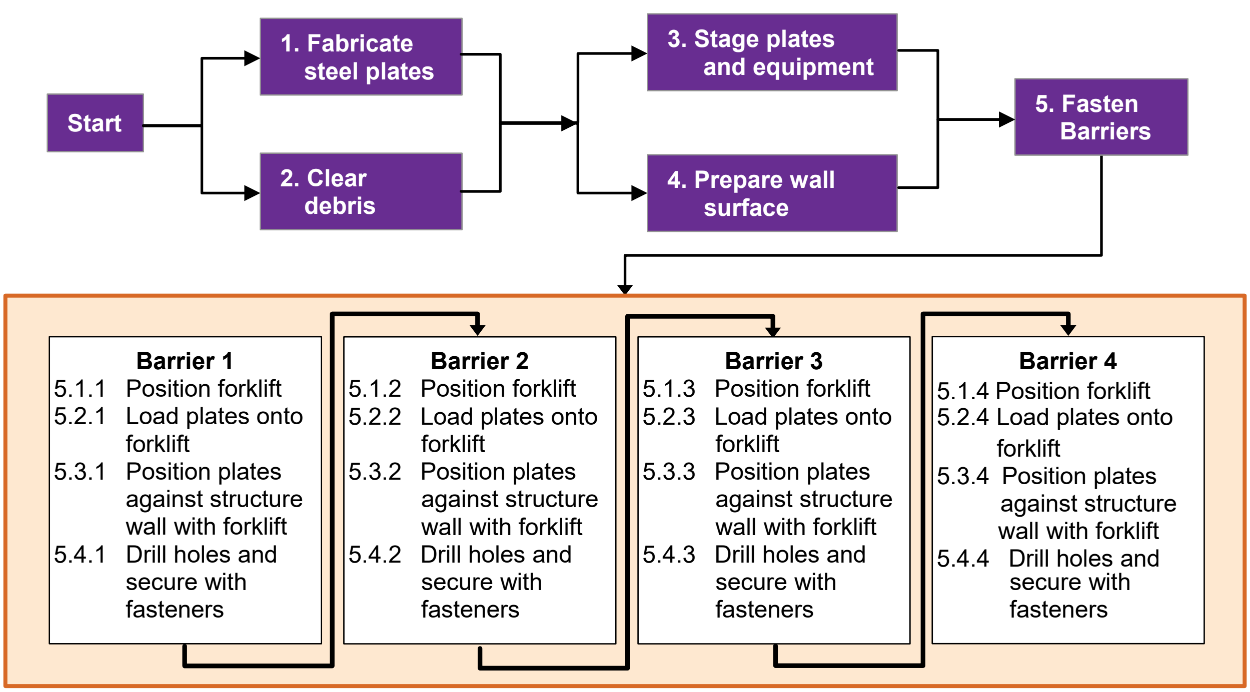


Figure 9.4 Workflow diagram for task 5: Fastening 4 barriers

Table 9.4 Baseline time for specific actions in Task 5

T_5: Task 5 Fasten Barriers		Baseline Time for 1 Barrier (min)		Baseline Time for 4 Barriers (min)	
Subtask	**SAs (for 1 barrier)**	**SA Time**	**Subtask Time**	**SA Time**	**Subtask Time**
B_1: 5.1 Position Forklift	S_1: 5.1.a. walking	5	15	20	60
	S_2: 5.1.b. getting in forklift	1		4	
	S_3: 5.1.c. driving	9		36	
B_2: 5.2 Load plates onto forklift	S_1: 5.2.a. loading plates	15	15	60	60
B_3: 5.3 Position plates against structure wall with forklift	S_1: 5.3.a. Position plates/driving	10	60	40	240
	S_2: 5.3.b. communicating the position	10		40	
	S_3: 5.3.c. positioning with forklift	20		80	
	S_4: 5.3.d. manual adjustment	20		80	
B_4: 5.4 Drill holes and secure with fasteners	S_1: 5.4.a drilling (hand tool)	15	30	60	120
	S_2: 5.4.b. bolting (hand tool)	15		60	
	Total Time (min)		**120**		**480**

Because the MA requires fastening four barriers, the process, which executes Subtask 5.1 through Subtask 5.4 along with all the associated SAs, is repeated for each of the four barriers (see Figure 9.4). In the example, the proof-of-concept method was illustrated for fastening one barrier only. Using the terminology of the proof-of-concept method, the highest level of analysis is a task, Task 5, performed for Barrier 1. This task, denoted by T_5, consists of four subtasks, Subtasks 5.1–5.4, denoted by symbols B_1–B_4. The subtasks are decomposed into SAs—three SAs make up Subtask B_1 (S_1– S_3), one SA makes up Subtask B_2 (S_1), four SAs make up Subtask B_3 (S_1–S_4), and two SAs make up Subtask B_4 (S_1–S_2). Notice that SAs are specific to the subtask of which they are part, even though their notations (indexes) may be the same.

Following the terminology outlined in the proof-of-concept method section, the baseline time for Task T_5 can be expressed as

$$\boldsymbol{t(T_5) = \sum_{l=1}^{4} t(B_l)} \tag{9-11}$$

where $l \in [1,4]$ is the index referring to the four subtasks that comprise T_5. Each of the subtasks' baseline time can be expressed as

$$\boldsymbol{t(B_l) = \sum_{k=1}^{n_S} t(S_k) = \sum_{k=1}^{n_S} \sum_{i=1}^{n_i} t_{i,k}} \tag{9-12}$$

The research team developed the baseline time with $t(S_k)\ k \in [1, n_S]$ for executing each SA under Task T_5, as shown in Table 9.4[6].

[6] Although the example MA came from a real life NPP flood protection and mitigation procedure, the research team had very limited information regarding this MA. The research team's estimates of SA performance baseline time is based on its collective familiarity with NPPs and other industrial settings. The research team acknowledges that these baseline times should be developed in close cooperation and active participation of the specific NPP staff.

The total baseline time for performing Task T_5 was estimated as 480 minutes and includes fastening all four barriers.

$$\boldsymbol{t(B_l) = \sum_{k=1}^{n_S} t(S_k)} \tag{9-13}$$

Where $k \in [1, n_S]$ is the index referring to the number of SAs that compose the *l*th subtask. In this example, for *l* taking values 1, 2, 3, and 4, the corresponding numbers of SAs n_s are 3, 1, 4, and 2, respectively. Therefore, the baseline time for Subtask *B₁* is

$$\boldsymbol{t(B_1) = 5 + 1 + 9 = 15} \tag{9-14}$$

minutes. The baseline times for the other subtasks were determined similarly (Table 9.4).

To estimate the impact of ECs on the performance demands, two sets of information must be developed: (1) performance demand weights w_i, *i*=1,2,3,…9, associated with each SA in this example task, and (2) the impact factor values $I_{i,k}$, associated with the set of prevailing ECs on each of the performance demands associated with an SA. Following Chapters 6 and 7, the successful completion of every SA can be construed as requiring one or more performance demands. The percentage contribution of the performance demands to the success of an SA is defined here as its "weight," w_i, i=1,2,3,…9. The total contribution of performance demands must equal 100 percent or 1.0. Therefore, as outlined in the previous section, an SA can be represented as a sum of the weights of all required performance demands. For example, the research team represented walking as 25 percent (w_1 = 0.25) of detecting and noticing and 75 percent (w_5= 0.75) of gross motor action. By comparison, positioning with a forklift was represented as 50 percent (w_4= 0.5) of fine motor action, and about 17 percent each of detecting and noticing (w_1 = 0.17) and understanding (w_2= 0.17), and 16 percent decision-making (w_3 = 0.16), respectively. Based on a research team discussion of the literature reviewed and based on expertise and experience (similar to an expert elicitation that might be conducted in an application of the method), the research team estimated performance demand weights associated with each SA (Table 9.5).

In this example, the research team assumed that only one EC, heavy rain, prevailed during performance of Task T_5 to estimate its impact on the various performance demands. Note that the research team conceptually differentiates between impacts from primary and secondary ECs. A prevailing EC might directly influence a performance demand (e.g., rain on an equipment gauge making it difficult to see, and therefore impacting detecting and noticing); the same EC may produce secondary conditions that might also impact performance demands (e.g., rain could lead to a slippery surface, cold temperature, or noise, which could then impact the performance of a fine motor action, such as gripping a tool with a slippery or cold surface, or oral communication due to an elevated level of noise).

The impact factor values associated with a heavy rain scenario on the performance demands are shown in Table 9.6. These values were based on the research team's best judgment and were intended for purposes of illustrating the proposed method only[7]. Recall that the value of

[7] These impact factors are for example only and not validated. They may not be representative of impact factors that might be measured from experience or estimated by a structured expert elicitation process.

Table 9.5 Performance demands associated with each specific action in Task 5

T_5: Task 5. Fasten 4 Barriers		Performance Demand Weights								
					4. Action			5. Teamwork		
Subtask	Specific Actions	w_1 1. Detecting & Noticing	w_2 2. Under-standing	w_3 3. Decision-making	w_4 4.1 Fine Motor	w_5 4.2 Gross Motor	w_6 4.3 Other	w_7 5.1 Reading /writing	w_8 5.2 Oral Comm.	w_9 5.3 Crew Interaction
B_1: 5.1 Position forklift	S_1: 5.1.a. Walking	0.25	0	0	0	0.75	0	0	0	0
	S_2: 5.1.b. Getting in forklift	0.25	0.25	0	0	0.5	0	0	0	0
	S_3: 5.1.c. Driving	0.17	0.17	0.17	0.5	0	0	0	0	0
B_2: 5.2 Load plates onto forklift	S_1: 5.2.a Loading plates	0.17	0.17	0.17	0.5	0	0	0	0	0
B_3: 5.3 Position plates against structure wall with forklift	S_1: 5.3.a. Position plates/driving	0.17	0.17	0.17	0.5	0	0	0	0	0
	S_2: 5.3.b. Communicating the position	0	0	0	0	0	0	0	0.5	0.5
	S_3: 5.3.c. Positioning with forklift	0.17	0.17	0.17	0.5	0	0	0	0	0
	S_4: 5.3.d. Manual adjustment	0.33	0	0	0.33	0.33	0	0	0	0
B_4: 5.4 Drill holes and secure with fasteners	S_1: 5.4.a Drilling (hand tool)	0.33	0.33	0	0.33	0	0	0	0	0.5
	S_2: 5.4.b. Bolting (hand tool)	0.33	0.33	0	0.33	0	0	0	0	0

Note: The time calculation is based on fastening one barrier; the research team notes the same actions should be performed for each of the four barriers.

Table 9.6 Example impact factor values associated with heavy rain

				4. Action			5. Teamwork		
EC: Heavy Rain	1. Detecting & Noticing	2. Under-standing	3. Decision-making	4.1 Fine Motor	4.2 Gross Motor	4.3 Other	5.1 Reading/writing	5.2 Oral Comm.	5.3 Crew Interaction
From Primary EC	1.3	1.2	1.1	1.5	1.4	1.1	1	1.2	1.3
From Secondary ECs	1	1	1	2	2	1	1	1	1

Note: In this heavy rain example, secondary ECs might include slippery surface for tools, equipment, plates, and ground, cold surface due to drop in temperature, and noise due to rainfall.

impact factors is equal to or greater than 1. An impact factor of 1 indicates the EC has no measurable adverse impact on a performance demand. An impact factor greater than 1 suggests an adverse impact on the performance demand. Consequently, the time it takes a worker to perform an action might be longer.

Using the research team's judged values of performance demand weights and impact factors for heavy rain, the proof-of-concept method was used to estimate the impacts on Subtask T_5. For this example, the research team only considered the impact from the primary EC. However, impacts from secondary ECs may sometimes exceed those from the primary EC (e.g., the research team estimated that the impact factor for fine and gross motor skills from slippery and cold surfaces presenting a challenge in gripping tools during heavy rain may exceed that from the presence of the rain itself). An approach for combining the impacts of primary and secondary ECs requires further development.

The affected time for Subtask B_1 of Task T_5 was computed as

$$\boldsymbol{t_*(B_l)} = \sum_{k=1}^{3}\sum_{i=1}^{9} \boldsymbol{I_{i,k} w_i t(S_k)} = \sum_{k=1}^{3} \boldsymbol{I_k^* \, t(S_k)} \tag{9-15}$$

where I_k^* is the impact factor for the *k*th SA, appropriately weighted by performance demand weights.

The SAs composing Subtasks B_1, S_1, S_2, and S_3 are themselves composed of 2, 3, and 4 performance demands, respectively, so the second summation in the equation above would have 2, 3, and 4 elements (for *k* =1, *I* =1 and 5; for *k* =2, *I* =1,2, and 5; and for *k* =3, *I* =1,2,3, and 4, respectively). Therefore, the affected time for Subtask B_1 is calculated as follows:

$$\begin{aligned} \boldsymbol{t_*(B_l)} &= \boldsymbol{(1.3 * 0.25 + 1.4 * 0.75) * 5 +} \\ &\quad \boldsymbol{(0.25 * 1.3 + 0.25 * 1.2 + 0.5 * 1.4) * 1 +} \\ &\quad \boldsymbol{(0.17 * 1.3 + 0.17 * 1.2 + 0.16 * 1.5 + 0.5 * 1.3) * 9} \\ &\boldsymbol{= 6.875 + 1.325 + 12.15} \end{aligned} \tag{9-16}$$

The resulting affected time for Subtask B_1 is 20.35 minutes. Similarly, the affected times for Subtasks B_2, B_3, and B_4 were computed (Table 9.7).

Adding the affected times for all four subtasks gives the affected time for Task T_5, $t^*(T_5)$ as 161.6 minutes versus a baseline time of 120 minutes. These results indicate that the impact of heavy rain on fastening one barrier could be expressed as an additional 41.1 minutes in performance time. If the 161.1 min affected time exceeds the available time to conduct the action, this could indicate a failure due to time. However, the available time to complete the action will be site- and event-specific, so cannot be assessed in this example. Similarly, if the baseline error rate for performing each SA is known, the same approach could be applied to estimate ECs' impact on overall task error rate.

This simple task provides a very limited opportunity to validate the method, given that no formal expert elicitation method or empirical data was used for estimating impact factor values and performance baseline time and the discussion of environmental condition impacting performance is limited to heavy rain. The U.S. Army manual estimated a reduction in effectiveness of 25-75% for moderate rainfall of 0.11-0.30 in/hr (US ARMY 1992). In this

Table 9.7 Specific action baseline times, impact factors, and affected times

Task 5 Fasten 4 Barriers		Baseline Time $t(S_k)$ (min)	SA Impact Factor I_k^* (Primary EC only)	Affected Time $t^*(S_k)$ (Primary EC Only)
Subtasks	**Specific Actions**			
5.1 Position forklift	5.1.a. walking	5	1.38	6.88
	5.1.b. getting in forklift	1	1.33	1.33
	5.1.c. driving	9	1.35	12.15
5.2 Load plates onto forklift	5.2.a loading plates	15	1.35	20.25
5.3 Position plates against structure wall with forklift	5.3.a. Position plates/driving	10	1.35	13.5
	5.3.b. communicating the position	10	1.25	12.5
	5.3.c. positioning with forklift	20	1.35	27
	5.3.d. manual adjustment	20	1.40	28
5.4 Drill holes and secure with fasteners	5.4.a drilling (hand tool)	15	1.33	20
	5.4.b. bolting (hand tool)	15	1.33	20
	Total Time	**120**		**161.59**

example, the performance effectiveness drops from 0.00833 tasks/min (1/120 min) to 0.00618 tasks/min (1/161.59 min), which is a drop to 74% effectiveness, within the range proposed by the Army. However, it should be noted that the range of reduction in effectiveness is broad, suggesting uncertainty that may results from individual characteristics and/or presence of other concurrent conditions.

The proposed EC impact assessment method could be applied to task success as well as time. It is similar to the IMPRINT taxon-based method in important ways. Both methods are based on a proportional weighting scheme to characterize a task or SA using performance demands (similar to taxons). Likewise, both quantify an impact multiplier to estimate the impact on performance in terms of performance time or accuracy. The proposed method described in this chapter, however, provides opportunities for generalizing the taxon-based method because it is not limited by the number of performance demands that can be used in characterizing any individual SA. Moreover, the development of the performance demand categories described in this volume incorporated research on HRA methods, which may be more comprehensive than the Army Research Laboratory (ARL) taxon-based method (see Section 5.2.4).

As discussed previously in Section 6.5, in order to use this approach with GAs, further research into developing GAs with stable performance demand profiles is needed. Development of GAs with stable performance demand profiles can be performed in consultation with and active participation of NPP personnel experienced in performing flood protection and mitigation procedures or through other methods such as data gathering from other industries or formal expert elicitation.

9.3 Using Results of the Research Literature Review

As noted in the previous section, the EC impact factors should ideally be estimated by empirical research in NPPs or other industries, and/or through rigorous expert elicitation methods (if empirical data are limited). Review of the EC impact literature (presented in Chapter 8) indicates that, in general, the research findings offer both qualitative and quantitative information of mixed utility; even quantitative information, for example, may not readily apply to the performance demands described earlier in this report. To organize and capture the findings from the research literature review, the research team identified four categories of information based on the research literature review results:

1. Quantitative information that is directly applicable to determining the quantitative impact of an EC on a performance demand and can be directly used to support the proof-of-concept EC impact assessment approach.
2. Quantitative information that is of less direct applicability in determining the quantitative impact of an EC on a performance demand. Some empirical studies might report EC severity limits which represent a threshold based on the magnitude of the EC. When an EC is below a lower limit, there is no discernible impact on human performance of a given activity; when the EC is above an upper limit, personnel cannot perform the activity at all. Under certain assumptions regarding the variation of impacts in accordance with changing levels of severity between the upper and lower limits, this information might be used with the proof-of-concept approach to provide usable information.
3. Qualitative information that supports the general observation that an EC affects a performance demand, but no quantitatively measured impacts of the EC on worker performance, including limits, are reported in the research literature. Such information could be used to make inferences about the relationship between an EC and performance as well as between intervening variables and performance. For example, if it is known that, in general, cognitive functions are impaired by an EC, a particular performance demand associated with cognitive functions, such as understanding, might be assumed to be impacted by the EC also. This information might be used to inform a sensitivity analysis using the proof-of-concept approach. Likewise, this information might be used in informing expert judgments.
4. No information. When no information about the impact of an EC on worker performance is reported in the pertinent research literature, it is noted as a research gap.

9.3.1 Directly Used Quantitative Information

Some studies included in the review offered quantitative information that is directly applicable to determining the impact of an EC on a task, or, ideally, individual performance demands. Depending on the type of available information, there are several ways to use it in the proposed proof-of-concept approach. In these cases, the impact of the EC is provided by a general algorithm in which a unit of degraded performance per unit of EC severity is defined:

$$Impact\ on\ performance\ demand = \frac{units\ of\ degraded\ performance}{units\ of\ EC\ severity} \qquad (9\text{-}17)$$

For example, Section 0of this report describes the impact of lighting on worker performance. The summary of the research literature explains that one of the effects of reduced lighting is an increase in time for the task of taking handwritten notes. Through an experiment on pencil-based note taking, a relationship was defined between reduced illumination (measured in footcandles) and the increase in time it took to complete a task involving note taking. Writing, which is a component of note taking, is part of a performance demand titled “teamwork” according to the taxonomy presented in Section 5.2.4. For this performance demand, the impact of poor illumination can be determined directly from this relationship based on experimental evidence. This relationship between level of lighting and performance time of a task could be used in an approach like the proof-of-concept approach presented in this chapter.

In another example, Section 8.2.8 describes the impact of precipitation on worker performance. The summary of the research literature explains that one of the primary effects of precipitation is reduction of visibility associated with either attenuation or reflection of light. Visibility is critical to one of the nine performance demands, detecting and noticing. However, although the relationship between the amount of precipitation and visibility was not defined in the research literature, a direct relationship between free-flow-speed (i.e., a driver's desired speed in low volume traffic with no traffic control devices) and rain intensity was specified in the pertinent research. The reported percentage reduction in free-flow speed could be used directly to assess the effect of precipitation on a task that involves driving as a whole rather than decomposing the task of driving into SAs to determine the effect of the precipitation on each performance demand. The reduction in speed could be correlated to a percentage increase in task performance time and such information could also be used in an approach like the proof-of-concept approach presented in this chapter.

In a last example, the impact of the EC can be applied directly to the action rather than the PDs that compose the task, subtask or SA. Section 8.2.9, for example, describes the impact of standing or moving water on worker performance. The literature summary explains that the most frequently studied effect of moving water on human performance is the effect of water depth and velocity on toppling a person who is attempting to stand or move in the water. The research literature provides an equation for an individual toppling while working in flowing water as a function of water velocity and depth. The team used this equation to determine the relationship between performance degradation and the specific level of EC severity (i.e., water velocity and flow depth). Using this equation, a safe walking velocity in 0.3 m deep water for an individual who is 1.8 m tall and weighs 82 kg is estimated to be 1.14 m/s, if the normal walking speed for the individual is assumed to be 1.34 m/s. From this information, the extended time it takes to travel a predefined distance may be estimated and compared to the time it takes to walk at a normal speed, holding all else constant. In this example, the individual is assumed to be walking against the current so that the speed at which the individual walks when added to the velocity of the water will not exceed the safe walking velocity of 1.14 m/s. For a distance of 300 m, the time it takes an individual to traverse the distance in the absence of any standing or moving water is 263 seconds (i.e., the baseline time) and it increases to 469 seconds if the individual walks in moving water at the velocity and depth defined in this example. This increase in the time it takes to walk suggests a direct correspondence between the research literature and the proof-of-concept approach presented in this chapter.

9.3.2 Indirect Quantitative Information

Some studies included in the review of the research literature offer quantitative information that is less useful for determining a unit of degraded performance per unit of EC severity. Typically, such quantitative information was provided as limits of human performance under the EC; that is, the EC severity limit above which personnel cannot perform an activity. This kind of information cannot be used directly in the proof-of-concept approach. However, it may be possible to extrapolate from the existing data or information to estimate a quantitative relationship between units of degraded performance versus units of EC severity. For example, if it is known that human performance cannot be reliably carried out or worker health and safety cannot be protected past a particular EC severity limit, then the impacts at levels of the EC less than the limit might be estimated. These estimates might then be used in an approach like the proof-of-concept approach presented in this chapter. The extrapolation is likely to contain significant uncertainty, which should be carefully evaluated for its effect on impact estimates.

Section 8.2.1 of this report, which describes the impact of heat on worker performance, illustrates an approach to using EC limits information to estimate performance impact. The review of the research literature shows that the recommended exposure limits are a function of wet bulb globe temperature (WBGT), workload, and exposure time. Curves are presented for “perceptual/motor” effects and “simple mental tasks effects” that show the WBGT versus exposure time limits of these performance demands (see Section 8.2.1.5 and Figure 8.2). An estimate of curves presenting low, medium, and high effects on these performance demands, as a function of WBGT versus exposure time, might be developed based on the recommended exposure limits. If the low, medium, and high effects can be converted into quantitative values (e.g., the percentage time increase or percentage error increase), then this information could be used in an approach like the proof-of-concept approach discussed above.

Another way to use the quantitative information indirectly, is to assume that performance fails at a particular EC severity limit. If the probability that a particular EC severity limit is reached can be determined, then this information could be used to determine the probability that a performance demand cannot be met. This information could not be used in the proof-of-concept approach that uses the increase in time as the unit of degraded performance, but it might be used in an approach in which the failure probability is the unit of degraded performance.

9.3.3 Qualitative Information

The research literature review shows that in some cases, only qualitative information about the impacts of ECs on performance demands or an SA exists. In these situations, an expert elicitation process might be used to elicit the best judgment from experts. If there is qualitative information in the research literature, it might be used to inform a sensitivity study using the proof-of-concept approach. Again, significant uncertainty is likely to exist in both the limits on EC severity and on the relationship between the EC severity and impact on performance demands. Sensitivity analyses assess how the uncertainty in the input of an analytical model impacts the outputs of interest. A sensitivity study might be used to determine the point at which the severity of the EC may be expected to have meaningful impact on the performance of an SA. It is possible that the output of interest (i.e., the impact of a specific EC on a specific SA) is not impacted in a meaningful way by the most likely severe EC that can occur at a given site.

For example, Section 8.2.5 of this report describes the impact of lighting on worker performance. The research literature summary explains that lighting, if inadequately bright or lacking certain spectral characteristics, can result in decreased alertness. In turn, it is noted that alertness is encouraged by higher intensity and shorter wavelength light, which is accompanied by improvements in a variety of cognitive tasks (compared to tasks performed when light is at lower intensities that do not contain short wavelengths). This finding is interesting because alertness is part of the detecting and noticing performance demand. Consequently, it is possible to use the proof-of-concept approach presented in this chapter to show that lighting could impact certain performance demands associated with alertness. For actions that do not require alertness, lighting might not be as important for performance where the detecting and noticing performance demand is important.

9.3.4 No Information

The research literature review identified that for some ECs of interest to NPP flood protection and mitigation MAs, no information is reported in the research literature. More research is needed in these “gap” areas to increase the scope and depth of the knowledge about these ECs and how they might affect worker performance. When such information becomes available, it can then be categorized for modeling purposes based on the categorization scheme and the modeling approach discussed earlier.

9.4 Limitations and Caveats

As stated earlier in this chapter, the impact assessment approach presented is meant to be a proof-of-concept exercise. The feasibility and validity of the approach remains to be explored because of a number of limitations and caveats that are discussed below.

Most notably, the performance demand weights and EC impact factors used to quantify EC impacts on worker performance require a sound technical basis. Ideally, these values should be informed by empirical research or through rigorous expert elicitation methods when empirical data are limited or not available. The review of the EC impact literature resulted in some quantitative and qualitative information that could be used by experts to estimate performance demand weights and impact factors. However, considerable gaps exist for this kind of quantitative information. Existing information that can be used to render and validate the impact assessment approach is also often limited. Nonetheless, as discussed previously in this chapter, the research team identified a few example ways to use existing qualitative and quantitative information from Chapter 8 in the proof-of-concept approach.
The research team notes that using the performance demand-based method requires analysts to create a map between each specific action and performance demand. Consequently, the mapping could be somewhat subjective and influenced by the analysts’ knowledge, experience, and professional judgment. If the mapping is performed by a group of experts with somewhat different judgments about performance demand weights, a consensus building process would be needed to reconcile the differences. During a group exercise in which the research team worked together to map performance demands with an SA, the team found that the resulting performance demands by percentage contribution associated with performing an SA were generally quite similar, albeit not identical among the team members. This encouraged the team because its members were diverse in discipline, training, and experience.

The proof-of-concept example does not include the occurrence of secondary ECs and their associated impacts. In the case of slippery surfaces (e.g., slippery tools or walking surfaces), condensation on instruments and other displays makes them difficult to read; localized phenomena (e.g., wind or water borne debris that creates obstructions) caused by the primary EC create challenges for the worker. Nonetheless, the research team proposes that the method for assessing primary EC impacts on worker performance presented in this chapter can also be applied to evaluate the impacts on worker performance from secondary ECs, if there is sufficient information in the research literature on the impacts from secondary ECs. Combining the impacts from primary and secondary ECs on performance demands requires further development. For example, when applying the method an analyst might also need to estimate the likelihood or conditional probability of the occurrence and severity of the secondary ECs stemming from a primary EC, though there may be adequate weather records for some ECs at or near the sight to estimate the conditional probability.

The proof-of-concept example did not fully address the complexity in task sequence and configuration, though an example using ARL's IMPRINT (ARL, 2017) demonstrates an existing software that allows evaluation of sequential dependence. An example developed and analyzed using IMPRINT Pro, v. 4.1 is described in Appendix D. The proof-of-concept example focused on an individual performing sequential SAs as the units of analysis. It did not address how the EC impacts parallel tasks or tasks that are jointly performed by a crew/team. The research team proposes that on the basis that the unit of analysis is an individual performing an individual SA, the relationship between tasks can be defined separately. For example, if two SAs (or tasks) are performed in parallel and both are required to successfully execute a manual action, then the individual impacts on the two SAs (or tasks) might be summed. On the other hand, if two SAs or tasks are performed in parallel and only one of them is required to successfully complete a manual action, then it might be appropriate to consider only the most limiting impact. Similarly, if two workers are required for the performance of an SA or task, then the impact of the SA or task on the MA might be combined.

The proof-of-concept example could be further expanded to address how recovery time stemming from worker errors could also contribute to the time required to complete the MA. It is possible that an EC could contribute to an error that, if undetected, could lead to failure of the MA. If the error could be detected and if enough time is available to correct the error, then the overall EC impact could also be operationalized as an extension in time for performing the MA. To capture the impact of an EC on error in terms of performance time, EC impact factors used to quantify EC impact on worker performance could be expanded from being based strictly on performance time to include performance errors as a basis for quantification. If information about performance errors exists, then the proof-of-concept approach could be adjusted to model recovery actions.

The proposed approach does not include the ability of the worker to adapt to the environment, nor does it consider performance degradation due to fatigue. Given the high physical demand of some of the MAs (e.g., sandbagging), it is possible that workers might become fatigued over time and crew rotation might be essential for accomplishing the MA. Further, the approach assumes adequate training and procedures. Finally, additional considerations such as the effects of dynamic (time varying) ECs and combinations of ECs during the performance of MAs, as well as uncertainties are not incorporated into the current approach illustrated earlier. These limitations present opportunities for improving and enriching the capability of the proof-of-concept approach.

9.5 Chapter Summary

In this chapter, the research team presented a proof-of-concept approach for quantitatively assessing EC impacts on worker performance measured in terms of performance time. Specifically, the research team applied the approach to an example MA to illustrate both the conceptual and computational feasibility of the approach. Based on the literature review reported in Chapter 8 and Volume II, the research team identified a number of approaches by which existing quantitative and qualitative information from pertinent studies could be used in the proposed approach. By building a bridge between the research literature and impact assessment quantification methods, the research team constructed and carried out an illustrative analytical example. Together, these efforts demonstrated the following:

1. Existing research findings can be leveraged to provide the technical basis for human performance impact quantification despite gaps and limitations.

2. The proposed approach, notwithstanding limitations, is theoretically and computationally tractable.
3. The proposed approach is conceptually and operationally consistent with the decomposition-aggregation approaches discussed in in this report and supports the implementation of the overarching EC impact assessment framework discussed in Chapter 7
4. For future research, opportunities exist to expand and enhance the proof-of-concept approach. They include the following:
    a. adapting the approach to account for both primary and secondary EC impacts on performance;
    b. modeling complexity in task sequence and crew performance;
    c. expanding the approach to model the time it takes to recover from critical worker errors which could lead to a significant extension in the time it takes to perform an MA;
    d. modeling the effects of multiple, simultaneously occurring ECs;
    e. modeling the effects of dynamic ECs;
    f. propagating uncertainties quantitatively; and
    g. addressing additional factors (e.g., fatigue, stress, learning, training and procedures) that might influence performance.

10 SUMMARY OF FINDINGS AND FUTURE DIRECTIONS

10.1 Summary of Findings

The purpose of this report is to provide a thorough review of the research literature along with characterizations of the flood hazards, the ECs that accompany them, and the manual actions (MAs) required for flood protection and mitigation. This goal is achieved through a conceptual framework that demonstrates a utility for assessing the impacts of environmental conditions (ECs) on human performance. The specific objectives of this project were to (1) characterize the MAs that may be performed at and around U.S. nuclear power plant (NPP) sites, with a particular focus on flood protection and mitigation activities carried out outside the main control room; (2) identify the ECs that may affect the performance of MAs and suggest metrics for characterizing them; (3) review the research literature and summarize the effects of ECs on human performance; and (4) apply lessons learned from previous studies, primarily those summarized in NUREG/CR-5680 (Echeverria et al., 1994) and more recently available information including those from other industries.

10.2 Characterizing Manual Actions and Performance

The research team compiled information about MAs that are part of NPP flood protection and mitigation procedures by examining (1) U.S. Nuclear Regulatory Commission (NRC) staff assessments of licensees' flooding walkdown reports, (2) five available individual NPP plant procedures (e.g., Abnormal Operating Procedures), and (3) a description of FLEX procedures. The research team reviewed NRC staff assessments from 60 NPP sites to obtain a high level, cross sectional understanding of salient MAs that appeared repeatedly in these documents. These MAs represent the actions most commonly included in flood protection and mitigation procedures. The compiled MAs were often complex, multistep activities involving both motor and cognitive demands. The MAs would often involve more than one task location and use of varying levels of hand tools and light and heavy equipment.

Drawing on human factors, ergonomics research, task analysis, and impact assessment literature, the research team concluded that a task analysis framework and approach, adapted from a method developed by the U.S. Army Research Laboratory and implemented in the software IMPRINT, offered a useful method for assessing the impact of the environmental conditions being addressed in this report. An example Manual Action was analyzed in a training example using IMPRINT Pro v4.1 and is described in Appendix D. Consequently, as described in Chapters 5 through 8, the research team applied this framework and approach in (1) reviewing the research literature to establish performance measures, worker ability, and task demand characteristics; (2) decomposing MAs into tasks, subtasks, and specific actions (SAs) and characterizing them in terms of the demands they impose on those performing them; (3) and summarizing what research was found about how the ECs that may prevail during flooding events affect performance demands and task performance. The team also discussed an extended framework to generalize specific actions when conducting an analysis across a large set of plants or for identifying what ECs might prevail during flooding events.

The research team developed a taxonomy of nine performance demands to characterize the abilities called upon and demands imposed by the MAs and their tasks, subtasks, and SAs. The team drew primarily from three sources in the development of the taxonomy: (1) NUREG/CR-5680 (Echeverria et al., 1994), (2) task taxonomy or taxons from O'Brien et al. (1992), and (3) macrocognitive functions described in NUREG-2114 (USNRC, 2016b).

The research literature indicates that it is at the level of performance demands that ECs impact performance. Consequently, the research team decomposed the MAs into progressively simpler components—tasks, subtasks, and SAs—so that the performance demands of the activities could be better understood and characterized. The decomposition process was based on review of human factors, task analysis, task taxonomy literature, and the judgment of the research team.

To establish a basis for sharing information across NPP sites and impact assessments, the research team described an approach that reviewed and aggregated an example set of specific actions into illustrative generalized actions (GAs) and proposed an approach for developing performance demand profiles of those actions. GAs are sub-sets of SAs whose performance demand profiles (i.e., the nature and proportional importance of performance demands) are sufficiently similar that an EC would impact them all similarly. The team noted that performance demand profile stability across differing ECs enhances generalizability and that decomposition to a level at which the performance demand profile of the GA is stable across varying ECs allows broad applicability (e.g., across NPP sites) of the information from the research literature about how ECs impact performance demands.

10.2.1 Characterizing Environmental Conditions

The research team compiled information about ECs that might prevail during floods of interest at U.S. NPPs; those floods that might trigger flood protection and mitigation procedures at NPPs. To accomplish this, the research team relied on its environmental and hydrometeorological expertise and experience gained from NRC siting and licensing reviews. Six ECs (humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning) in addition to the five ECs (i.e., heat, cold, noise, vibration, and lighting) cataloged in NUREG/CR-5680 (Echeverria et al., 1994) were identified. ECs can occur in combination (e.g., heat with humidity, cold with precipitation and wind). Some ECs can also produce secondary ECs (e.g., ice and snowpack can result in slippery surfaces, wind and water can carry debris).

10.2.2 Characterizing the Effects of Environmental Conditions on Human Performance

As described in Chapter 8, the research team compiled an overview chart to systematically describe ECs, attributes and units of measurement for the ECs, mechanisms by which the ECs affect human performance, the aspects of human performance affected by the ECs, and potential mitigation of the ECs' adverse effects on human performance, safety, and health. The purpose of the overview was to (1) clearly articulate the dimensions of ECs and their effects, and (2) structure the review of human performance effects from prevailing ECs.

The review of the human performance literature suggested that there are two broad categories of EC effects on human performance pertinent to this report: (1) physical forces that mechanically interfere with motor functions (e.g., the impeding effects of flowing water and blowing wind), and (2) internal responses that primarily act through neurophysiological and psychological pathways (e.g., slowing of motor and cognitive functions under elevated heat or cold). The research team identified four levels at which information regarding the effects of ECs on human performance are described in the research literature:

- Level 1: Information that is directly applicable to determining the quantitative impact of an EC on human performance (e.g., for ECs such as wind and standing and moving water, that primarily act via a physical force).

- Level 2: Information that is of some applicability in determining the degree of impact of an EC on human performance (e.g., in some cases, EC severity limits may be available: below a lower limit, there is no discernible impact and above an upper limit, personnel cannot perform an activity at all).
- Level 3: Information that is qualitative. General agreement exists in the research literature that the EC affects human performance, but the measured impacts are not reported in literature, not even for severity limits.
- Level 4: The absence of information (a research gap).

In some cases, multiple levels of information are reported for particular EC- performance demand combinations reflecting the variability in the level of quantification available for different elements composing the performance demands.

10.2.3 Lessons Learned

In Chapter 7 the research team presents a conceptual framework that identifies the key components and relationships of an analytical approach or model to assess the effects of ECs on human performance. The framework is comprehensive in that it is designed to address MAs and ECs across all U.S. NPP sites. In applying the framework to the assessment of impacts of ECs on MAs at a specified NPP site, only a subset of the information and relationships may be pertinent because of site-specific hydrometeorological, logistic, site layout, and reactor design factors. At this point in the research, because the extensive site-specific information needed for a site-specific assessment is not available, application of the framework to a specific site has not been attempted. However, considering the MAs and ECs addressed in this report, the research team has concluded that the most useful measure of performance impact, of the two reviewed, is likely to be related to performance time rather than error rates. This is a divergence from the focus of most impact assessment research for the nuclear power industry.

Based on the example application of the proposed approach (described in Chapter 9), the research team identified the following limitations and caveats:

1. Establishment of performance demand profiles can be influenced by the analyst's knowledge and experience. Additional empirical research, systematic expert elicitation, and data from previous profiling efforts can assist in refining this approach.
2. EC impact factors should be further validated with additional empirical research and expert elicitation.
3. The example did not consider co-occurring ECs and/or secondary ECs because a strong procedural empirical base is lacking to support such analysis.
4. Task complexity was minimized, in keeping with the intent of the example; e.g., subtasks and SAs were sequential, no parallel or repetitive subtasks or SAs were considered, and no recoveries from failures of subtasks or SAs were considered. It is anticipated that software support (such as that provided by IMPRINT) would be needed to quantitatively evaluate more complex tasks. An example of a more complex scenario including recovery is shown in Appendix D.
5. Time and locational variations of ECs were not considered.
6. Uncertainties in performance demand weights for SAs, impact factors for SAs, baseline times for the SAs, and the severity of the EC were estimate in the proof-of-concept example but have not been validated by observation or other methods.

While reviewing and summarizing the research literature related to the impacts of ECs on human performance, the research team found that only 8 out of 99 combinations of ECs and performance demands have information that is directly applicable to quantitative impact assessment (Level 1). A further 29 combinations have information that is of some applicability in determining the degree of impact (Level 2), 43 combinations have information that is qualitative (Level 3), and 44 combinations have information gaps (Level 4)[1].

The team concluded that significant research gaps exist in the human performance research literature. Relatively modest progress has been made in quantifying the effects of ECs across the range of performance demands pertinent to MAs since preparation of NUREG/CR-5680 (Echeverria et al., 1994). The literature search did not identify any large scale ongoing or upcoming research programs from which major advances might be expected. Consequently, it appears likely that progress will be largely incremental in the upcoming years. Therefore, application of the framework presented in this report would require analysts to be innovative and to call upon data and knowledge from past experience with severe weather conditions and impact assessments from other industries and contexts. A structure expert judgement method, such as the expert elicitation method described in Xing et al. (2015) is recommended for deciding and characterizing uncertainties of decomposition and aggregation choices as well as performance demand weights and impact factors where there is limited operational experience or existing human performance quantification available.

10.2.4 Applying Available Knowledge for Impact Assessment

Use of available quantitative characterizations of the impacts of ECs on performance demands is recommended where Level 1 quantitative information is available. Competing quantitative characterizations may be available, reflecting uncertainty in the human performance technical community's knowledge, variations in experimentation and data collection methods, and/or the purpose and focus of those experiments and studies. To the extent possible, application of quantitative characterizations should take into consideration correspondence between research results and the particular elements of the performance demand pertinent to the task being assessed (e.g., whether visual or aural sensation is important).

For EC-performance demand combinations where Level 2 information is available, the analyst may need to adapt and/or extend[2] the available information about limits to characterize the quantitative relationship between ECs' severity and the corresponding impacts on performance demands. In these instances, two approaches may be available to adapt and extend some of the limited information:

- Conduct additional research focused on characterization of impacts between known upper and lower limits.
- Establish quantitative impact relationships based on elicited experience and data from workers and subject matter experts.

For EC-performance demand combinations where Level 3 or 4 information is available, additional information may be needed that would require additional research. Unfortunately, for some ECs, difficulty in reproducing appropriate field conditions or ethical considerations may

[1] Counts for the four levels do not add to 99 because for some of the EC-PD combinations, multiple levels are assigned.

[2] Adaptation may involve interpolation between known upper and lower levels of ECs or extrapolation beyond the range of data available in the research literature

preclude the conduct of research that would address the range of ECs pertinent to external flooding events. In these cases, it may be useful to prioritize the relative importance of ECs and performance demands on human performance of relevance to NPP flood protection and mitigation procedures. Relative importance of ECs may be prioritized by employing sensitivity analyses. ECs that result in insignificant impacts on human performance related to NPP flood protection and mitigation procedures can be fixed in severity at a nominal level and resources may be spent on more accurate characterization of ECs that have a greater range of impacts on human performance. Sensitivity analyses require a structured framework to gauge the relative importance of ECs and the proposed framework could be used for these analyses. Sensitivity analyses also require a framework that is quantitative; the proof-of-concept method could serve as the starting point to develop a quantitative approach to sensitivity analyses[3].

10.3 Future Research Opportunities

The research team identified three major opportunities for near-future research by drawing on the lessons learned from review of human performance literature, review of currently available approaches for human performance impact assessment and thought exercises to develop the proof-of-concept method based on the proposed framework. These three opportunities are addressing gaps in human performance literature, implementing sensitivity analyses and addressing uncertainties.

10.3.1 Addressing Gaps in Human Performance Research Literature

As noted earlier, significant gaps exist in the human performance research literature with respect to the EC-performance demand combinations enumerated in Chapter 8. Although research, especially experiments, may be difficult or sometimes nearly impossible to perform for some of the ECs (e.g., lightning), promising new avenues have been identified (e.g., personnel workload and attentional demand approach). The research team identified several ways to address gaps: (1) research on discomfort, anxiety, and perception of risk may have reached a stage where focused studies to address their effects can be productive; (2) identification of common underlying mechanisms across ECs may reveal similar patterns of impact across several performance demands; and (3) direct estimation approaches could offer a rapid method for scaling attentional loads for different ECs or combinations of ECs.

The challenge still remains to prioritize the allocation of resources for those ECs and performance demands that affect the flood protection and mitigation MAs the most. As mentioned earlier, a structured, quantitative approach to performing sensitivity analyses within the proposed framework, combined with elicitation of experience and observations from NPP personnel, could rapidly advance this goal.

10.3.2 Implementing Sensitivity Analyses

To identify ECs, combinations of ECs, and performance demands that most affect the flood protection and mitigation MA performance, a sensitivity analysis approach expanding upon the proof-of-concept method described in Chapter 9 could prove productive. A number of steps could be taken to obtain information that would support such a sensitivity analysis[4]:

[3] Task network modeling and human performance impact assessment tools are currently available, such as IMPRINT.

[4] Implementing items 1 and 2 could proceed in parallel with item 3 identified in Section 10.2.1.

1. Expand the proof-of-concept method to include treatment of multiple ECs, time varying ECs, secondary ECs, and task complexity.
2. Develop a method and guidelines for estimating the contribution of performance demands for SAs.
3. Collaborate with the nuclear power industry to obtain:
   a. better understanding of NPP flood protection and mitigation procedures;
   b. lessons learned from experiences while implementing flood protection and mitigation procedures during past floods, including the severity of ECs encountered;
   c. better understanding of operating crew training, composition, and the command structure in place while performing flood protection and mitigation procedures;
   d. better understanding of baseline times for performing flood protection and mitigation MAs and the factors affecting them;
   e. better understanding of opportunities for recovery actions from failures during flood protection and mitigation procedures;
   f. better understanding of tools and equipment used in flood protection and mitigation procedures; and
   g. testing the method against operating experience data or training runs to establish the validity of the method.

The proposed sensitivity analyses would require use of a quantitative, dynamic, task event analysis tool suitable for implementing our impact assessment approach. Because the goal may be to identify ECs that could most affect NPP flood protection and mitigation MAs across all NPPs, the sensitivity analyses would need to address the range of ECs and a variety of MAs. Insights gained from collaboration with the nuclear power industry are anticipated to be crucial.

10.3.3 Addressing Uncertainties

Significant uncertainties exist in the components of the impact assessment approach. These uncertainties can significantly affect the estimated impacts and therefore should be carefully addressed within the sensitivity analyses. The uncertainties in estimated impacts can arise from several causes:

- uncertainties in estimates of the flood parameters and ECs associated with a flooding event, including lead time and available time;
- uncertainties arising from incomplete understanding of the flood protection and mitigation procedures and their implementation during a flood of interest, leading to uncertainties in task analysis including performance demand weights;
- uncertainties in estimation of baseline performance times; and
- uncertainties in the technical community's understanding of the mechanisms of action and the degrees of impacts of ECs on performance demands.

Although not addressed explicitly in the proposed framework, approaches exist to account for variations arising from uncertainties in the factors listed above; e.g., using a structured Monte Carlo simulations approach. Explicitly carrying the uncertainties through the impact assessment could provide additional insights to inform the prioritization of future research.

11 GLOSSARY

acclimation – The process by which an individual organism adjusts to a change in its environment (such as a change in altitude, temperature, humidity, photoperiod, or pH), allowing it to maintain performance across a range of environmental conditions.

anticipatory action – actions completed in preparation for the occurrence of an event based upon the receipt of notification of the event due to the availability of warning time.

A-weighted decibel (dB(A)) – A weighted scale based on frequencies around 3,000 Hz to which the human ear is most sensitive that is often used when referring to the subjective loudness of noise.

catecholamines – Any of a class of aromatic amines that includes a number of neurotransmitters such as epinephrine and dopamine.

clothing thermal insulation index (Clo) – A measure of the insulating value of clothing. One Clo affords 13°F (~7°C) of protection from cold.

coefficient of friction (COF) – The ratio between the force necessary to move one surface horizontally over another and the pressure between the two surfaces.

color rendering index (CRI) – A scale from 0 to 100 percent indicating how accurate a given light source is at rendering color when compared to a reference light source. The higher the CRI, the better the color rendering ability.

contrast – In lighting, the ratio of the luminance of an object and the luminance of its background (e.g., how different the luminance of an object is from the luminance of its background).

decibel – The most common unit of measurement for the intensity of noise.

decomposition (of a manual action) – Analysis that deconstructs a manual action into tasks, subtasks (if necessary), and specific actions for the purpose of assessing the impact of environmental conditions on human performance.

design-basis flood – A flood caused by one or a combination of several hydrometeorological, geoseismic, or structural failure phenomena, which results in the most severe hazards to structures, systems, and components important to the safety of a nuclear power plant.

detection limit – The lowest quantity of a substance that can be distinguished from the absence of that substance (a blank value) within a stated confidence limit (generally 1%).

direct estimation method – Convergent method (psychophysics) broadly employed for directly scaling the magnitudes of a set of stimuli either (1) in terms of proportional numbers relative to each other or 2) by cross-modal matching to the magnitude of stimuli in another sensory or cognitive dimension.

dual task – A procedure in experimental (neuro)psychology that requires an individual to perform two tasks simultaneously, typically in order to compare performance with single task conditions.

duration – see flood event duration

effective temperature (index) – A single figure index reflecting the sensation of warmth that considers the combined effects of temperature, humidity, and wind.

environmental condition (EC) – The condition, due to an environmental phenomenon (e.g., from weather), that could exist during a flood of interest with a potential to affect human performance. Examples: heat (air temperature of 85°F), cold (air temperature of 30°F).

primary EC – An EC that does not require any other condition in order to affect performance. Examples: heat, cold.

secondary EC – An EC that would not occur without one or more primary ECs. Examples: slippery surface, mud.

environmental stressor – A stressor found in one's surroundings.

FLEX – Diverse and Flexible Coping Strategies.

flicker – The light-dark sequence created by very quickly switching a lighting source on and off.

flood event duration – "[t]he length of time in which the flood event affects the site, beginning with notification of an impending flood (e.g., a flood forecast or notification of dam failure), includes preparation for the flood and the period of inundation, and ending when water has receded from the site and the plant has reached a stable state that can be maintained indefinitely" (USNRC, 2012b, 2012d).

flood of interest – For the purpose of this report, a flood resulting from an event that would trigger initiation of flood protection or mitigation procedures at a nuclear power plant.

flood causing mechanism (FCM) – Flooding from a particular source, such as storm surge, dam failure, or local intense precipitation.

flood hazard – Conditions that facilities of a nuclear power plant may be exposed to during a flood event such as hydrostatic and hydrodynamic forces, debris accumulation, and impact forces that should be considered in the design to prevent loss of functionality.

flooding walkdown report – A report prepared by a nuclear power plant licensee to describe results of inspections to identify compliance with current design bases related to flooding.

flood protection and mitigation procedure – Any plant operating procedure (standard or abnormal) that implements external flood prevention, protection, or mitigation activities. For example, flood prevention activities (e.g., placement of sandbags or monitoring and clearing storm drains) are often contained in "adverse weather" or similar operating procedures.

generalized action (GA) – An individual component of a task or subtask that is sufficiently simple to evaluate the impact of ECs on human performance. GAs are general in nature, site-independent, and function as “building blocks” that can be used for recomposing or decomposing other manual actions.

glare – An intense or bright light that causes a reduction in visibility of a visual target.

hand-arm vibration syndrome – A painful and potentially disabling condition of the fingers, hands, and arms caused by exposure to vibration, initially indicated by a tingling sensation and numbness in the fingers.

Heat Index – An index that combines air temperature and relative humidity, in shaded areas, to determine the human perceived equivalent temperature, i.e., how hot it would feel if the humidity were some other value in the shade.

homeostatic mechanisms – Mechanisms that help regulate body heat to enable it to be in a steady state. The main mechanisms of homeostasis are body temperature, body fluid composition, blood sugar, gas concentrations, and blood pressure.

homeostasis – The tendency toward a relatively stable equilibrium between interdependent elements, especially as maintained by physiological processes.

human error – Any human action that exceeds some limit of acceptability, including inaction where required, excluding malevolent behavior. These include “slips” (e.g., pushing wrong button inadvertently), “lapses” (e.g., forgetting to add a recipe ingredient), and mistakes (not leaving enough room for a turn or understanding the consequences of an action).

human error probability (HEP) – A measure of the likelihood that plant personnel will fail to initiate the correct, required, or specified action or response in a given situation, or by commission performs the wrong action. The HEP is the probability of the human failure event.

human failure event (HFE) – A basic event that represents a failure or unavailability of a component, system, or function that is caused by human inaction, or an inappropriate action (ASME/ANS, 2009).

human reliability – The probability of successful performance of only those human activities necessary to make a system reliable or available.

human reliability analysis (HRA) – A structured approach used to identify potential human failure events and to systematically estimate the probability of those events using data, models, or expert judgment.

humidity – The amount of water vapor contained in a volume of air (usually expressed relative to the amount potentially contained, i.e., relative humidity).

hydrometeorological conditions – Characteristics including climate, terrain, soils, and proximity to waterbodies that influence floods at a location of interest.

hypothermia – The condition of having an abnormally low body temperature, typically one that is dangerously low.

luminance – The total luminous flux incident on a surface, per unit area; a measure of how much the incident light illuminates the surface, wavelength-weighted by the luminosity function to correlate with human brightness perception.

impact factor – A numerical measure of the increase in time to perform a specific action or the increase in error rate for performing a specific action.

inverted-U effects or relationships – A measure of performance relative to external effects. Performance increases with physiological or mental arousal, but only up to a point. When levels of arousal become too high, performance decreases. The process is often illustrated graphically as a bell-shaped curve that increases and then decreases with higher levels of arousal.

light intensity – The amount of energy emitted from a light source; the amount of illuminance from a light source.

luminance – A photometric measure of the luminous intensity per unit area of light traveling in a given direction; a description of the amount of light that passes through, is emitted by, or reflected from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square meter (cd/m^2).

manual action (MA) – For the purposes of this project, a distinct group of interrelated tasks that are performed outside the main control room to achieve an operational goal.

mechanism of action – the process through which an environmental condition has its effect on human physiology and/or cognition, and thereby human performance.

mental model – A person's internal, personalized, contextual understanding of how something works (i.e., a psychological representation of external reality) that is hypothesized to play a major role in cognition, reasoning, and decision-making.

Monte Carlo simulations approach – A method for estimating the distribution of outputs from a complex system using randomly sampled inputs to repeatedly perform system model simulations.

neurochemicals – Organic molecules, such as serotonin, dopamine, or nerve growth factor, that participate in neural activity.

neurophysiological functions – The functions of the human nervous system that are associated with coordinated physical and cognitive performances. Nerve conduction velocities, evoked potentials, and brain imagery represent some of the various measures of nervous system functions. These measures have been found to be adversely affected by exposure to environmental conditions (e.g., cold leading to hypothermia and slowing of nerve conduction velocities, cortical evoked potentials, as well as degradation of fine motor and gross motor performance).

noise – Unwanted, unpleasant, or annoying sound.

operator workload – Programmatic assessment of the extent to which the tasks performed by an individual use their limited processing resource (especially attentional, cognitive).

overtraining – Repetition of a skill until it tends to be largely performed automatically leaving the conscious mind available to focus on other things (also overlearning).

perception of risk – The subjective judgment people make about the characteristics and severity of a risk.

performance demand – The range of human physiological and cognitive abilities that are called upon to meet task requirements–performance degradation factor– Akin to a performance influencing factor or performance shaping factor, an aspect that serves to degrade the quality of human performance without specific reference to increasing or decreasing human error.

performance influencing factor (PIF) or performance shaping factor (PSF) – a factor that influences human performance and human error probabilities, including time available, stress/stressors, complexity, experience/training, procedures, ergonomics/human-machine interface, fitness for duty, and work processes (NUREG/CR-6883, Gertman et al., 2005)

permissible exposure limit – The legal limit in the United States for exposure of an employee to a chemical substance or physical agent.

phonological loop segment of working memory – The part of memory that deals with acoustic information such as speech and the interpretation of written words.

physiological collapse – Bodily collapse or near collapse with an inability to physically continue task performance.

probabilistic risk assessment (PRA) – A systematic method for assessing the likelihood of accidents and their potential consequences.

product number – The product of water velocity and depth that has been found experimentally to be strongly related to the probability of toppling a standing individual.

recommended alert limit – Heat stress alert limits recommended by the National Institute for Occupational Safety and Health for non-acclimatized workers.

recommended exposure limit – Heat exposure limits recommended by the National Institute for Occupational Safety and Health for acclimatized workers.

relative humidity – The amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature.

response time – The duration between the time a threshold for flood-response action is reached and the time the action must be completed.

reticular activating system – A set of connected nuclei in the human brainstem that is responsible for regulating wakefulness and sleep-wake transitions and serves in mediating attention and the “fight-or-flight” responses.

seiche – An oscillation of the water surface in an enclosed or semi-enclosed waterbody initiated by an external cause.

shear force – A force that acts along a surface (e.g., wind stress on a water surface) or unaligned forces causing a body to slide (e.g., pressure from water acting perpendicular to the vertical weight of a standing individual).

significance determination process (SDP) - The process used by the NRC staff to evaluate inspection findings to determine their safety significance.

slipperiness – The condition of surfaces or objects that are difficult to hold firmly or stand on because they are smooth, wet, or slimy; conditions that may cause a foot to slide and may result in injury or harmful loading of body tissues due to a sudden release of energy.

snowpack – Accumulated snow on the ground or other surfaces.

specific action (SA) – An individual component of a task or subtask, carried out in a site-specific task context, that is sufficiently simple to evaluate the impact of environmental conditions on human performance. SAs are site-specific and are obtained by decomposing site-specific manual actions.

sunny-day failure – dam failure due to non-hydrologic, non-seismic causes.

task – In the context of the decomposition of manual actions, one step of a manual action that has a distinct outcome or predetermined objective contributing to accomplishment of the manual action. A task is logically organized into cognitive and manual actions and generally requires both motor and cognitive abilities.

taxons – A taxonomic human performance category, especially as employed in the IMPRINT (Improved Performance Research Integration Tool) software.

taxonomy – A structured scheme of classification.

thermal balance – The state of a system at which inflowing and outgoing heat fluxes are in balance.

threshold flood response time – the duration between notification of impending flood or inundation/ponding and the time a threshold for flood response action is reached.

threshold limit value (TLV) – The level to which it is believed a worker can be exposed to a chemical substance day after day for a working lifetime without adverse effects.

toppling threshold – Conditions under which toppling of the human body is imminent.

tsunami – A series of water waves caused by the displacement of a large volume of a body of water, typically an ocean or a large lake.

turbidity – The cloudiness or haziness of a fluid; the relative clarity of a liquid.

VO_2 max – A measure of the maximum volume of oxygen that an athlete can use (usually measured in milliliters per kilogram of body weight per minute).

warning time – The time from when the event is known to present a threat to the plant (i.e., triggers) and the time when conditions could exceed permanently installed protections.

wetbulb globe temperature (WBGT) – A type of apparent temperature used to estimate the effect of temperature, humidity, wind speed (wind chill), and visible and infrared radiation (usually sunlight) on humans. It is a common measure of occupational heat stress.

wind chill index – The apparent temperature felt on the exposed human body owing to the combination of actual air temperature and wind speed.

vibration – An oscillating motion that serves to transfer mechanical energy.

visibility – The clearness with which objects can be seen; the relative ability to be seen under given conditions of distance, light, atmosphere, etc.

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APPENDIX A
MANUAL ACTIONS FROM NRC STAFF ASSESSMENTS OF NEAR-TERM TASK FORCE RECOMMENDATION 2.3: FLOODING WALKDOWNS

The research team reviewed and summarized flooding walkdown reviews across U.S. NPPs to obtain a high-level understanding of the salient MAs that occurred repeatedly in the reviewed documents.

As a consequence of lessons learned from events following the 2011 Tohoku earthquake and subsequent tsunami, the NRC requested flooding walkdown reports from power reactor licensees and holders of construction permits. Specifically, the NRC asked licensees and construction permit holders to conduct flooding walkdowns to identify and address degraded, nonconforming, or unanalyzed conditions and to verify the adequacy of the monitoring and response procedures. The NRC evaluated the submitted information and summarized it for each NPP in a staff assessment.

The research team reviewed, extracted, and compiled the actions, including manual and main control room actions pertaining to flood protection and mitigation, into a matrix. The actions included in the matrix below are the most commonly documented in external flooding responses across the staff assessments and are the core example set of MAs in this report.

Table A.1 Manual actions from NRC Flooding Walkdown Staff Assessments

A checkmark in the matrix indicates its presence in the staff assessment for that facility. In cases where the staff assessment indicates no MAs are required (e.g., if the staff found that "…the site does not have temporary barriers and other manual actions requiring [personnel] action"), the matrix was left empty

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
ANO1 and ANO2	"[I]nstallation of a jumper connection by a third-party vendor to maintain offsite power when water level exceeds 356 ft." Licensee did not explicitly state whether water level measurements (up to 350 ft.) and closure of openings and penetrations to flood protected structures were manual or automatic actions after water levels reach 350 ft.								X		X	
Beaver Valley	"L[l]icensee stated that the closure of the flood doors of the Intake Structure is the only [personnel] action that is performed for the protection of safety related equipment required for safe shutdown."			X								
Browns Ferry	The licensee reported that the BFN site has several temporary barriers and other manual actions that require [personnel]action: • The exterior doors to the Diesel Generator Buildings for BFN Units 1, 2, and 3 are normally closed and latched in the watertight position. However, if one of the exterior doors cannot perform its flood protection function, a portable bulkhead is available to seal an interior doorway between the affected room and the rest of the Diesel Generator rooms. The interior door must be		X	X	X							

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Browns Ferry	removed and the portable bulkhead bolted over the doorway. • The Reactor Building has a flood gate located outside the equipment access lock that would be lowered into place in the event of a flood. • The doors between the Radioactive Waste Building and the Service Building and between the Radioactive Waste Building and the Turbine Building are manually operated; the doors are normally closed but must be manually latched to be watertight. • Other manual actions for flood protection include operating or securing drain plugs, valves, equipment hatches, & manhole covers.											
Brunswick	"The site has temporary barriers and other manual actions that require [personnel] action, including closing or verifying closed flood doors and installing flood barriers. Sandbags are noted to be used within the procedure but are considered an above design-basis flood protection feature."	X	X	X								
Catawba	"The licensee did not identify any temporary barriers in its walkdown report that require manual [personnel] actions in the event of a flood threat. However, the licensee stated that a CAP action was identified to add steps to the "Plant Flooding Procedure" for manually closing Auxiliary Service Building doors AR5 and AR6 during ·a flooding event. In addition, another action was entered in the CAP to have an appropriate		X	X								

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Catawba	temporary barrier available to block the openings of these doors in the event that they cannot be manually closed."											
Clinton	"For the power block elevation, the licensee did not identify any credited temporary barriers that require [personnel] action in the event of a flood threat." "However, at the circulating water screen house, the licensee stated that the SSW "B" pump room is equipped with a floor hatch at elevation 699 ft to provide access to the SSW tunnel underneath. The licensee further noted that the open hatch cover must be installed prior to lake level reaching the 699 ft elevation to prevent flooding of the SSW "B" pump room. A CPS procedure requires monitoring of the SSW tunnel by the licensee for leakage when the lake water level reaches 694 ft."		X									X
Cooper	"The licensee reported that the site has temporary barriers and other manual actions that require [personnel] action. The actions/barriers include temporary passive features. The licensee stated that these features include hardened flood barriers (aluminum stop logs, etc.) and secondary protection through the deployment of sand bags erected per CNS Procedure 7.0.11 to protect doorways, normal access openings within structures and other critical site assets from a PMF."	X	X									

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Diablo Canyon	"The licensee reported that the site has no temporary barriers. The only manual actions associated with protection features involve having an individual available to close any watertight doors and having someone function as an active participant in conjunction with the tsunami warning procedure."			X								X
Dresden	"The walkdown report describes the use of temporary barriers and manual actions for flood mitigation, include the following: • Enter a plant flood emergency procedure when river levels are predicted to exceed elevation 509 feet MSL within 72 hours. This prediction is determined from monitoring the National Weather Service forecasts, U.S. Army Corps of Engineers forecasts at nearby dams, or Exelon's own weather monitoring systems. • When flood levels are predicted to exceed 509 ft MSL within 3 days, the units are shutdown, and vessel slow fill procedures are initiated. • If flood levels reach 509 ft MSL without sufficient warning, reactor scram is initiated. • When flood levels reach 509 ft MSL the following steps are initiated: ○ two Unit 2 service water pump motors are removed and relocated to above 530 ft MSL for post flood service; ○ the emergency make-up pump is setup in the center of Unit 2 reactor building equipment hatch,	X				X	X		X			X

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Dresden	which includes building scaffolding, lifting the pump with a crane, and staging additional diesel fuel; and valves in the fire protection system are configured to connect the pump to the system. ○ a sandbag berm will be constructed around the building for the isolation condenser make-up pumps. • At flood levels of 513 ft MSL, procedures are initiated to secure service water pumps, transfer reactor cooling to the isolation condenser, and address loss of fuel pool cooling. • At flood levels of 517 ft MSL, all transformers and electrical equipment will be deenergized and reactor doors will be opened to permit uninhibited flood water flow through the plant. • Before flood levels reach 517 ft MSL, vents on below ground diesel tanks are sealed, below ground water storage tanks are filled with water, and motor boats for transportation are secured. • The diesel emergency make-up pump is started when flood levels reach 518 ft MSL to provide make-up water to the isolation condenser. The pump is raised and lowered from the crane as flood waters rise and recede.”											

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Duane Arnold	"The licensee reported that the site has temporary barriers and other manual actions that require [personnel]action. The temporary active features include temporary sump pumps that are placed in sump pits and catch basins behind specified exterior doors in the plant to control in-leakage per the station flood protection procedure."		X			X						
Fort Calhoun	"The licensee stated that the site has temporary barriers and other manual actions that require [personnel]action. The actions and barriers include temporary and active features that require implementation of a procedure for performance of [personnel] actions in order for the feature to perform its intended flood protection function. These features include flood doors, removable metal barriers for protection of the Auxiliary Building and Intake Structure, and the associated tools required to install these barriers."		X	X								
Ginna	The licensee reported that the site has temporary barriers and other manual actions that require [personnel] action. The actions/barriers include: installing a temporary curb in front of two Auxiliary Building access doors and installing a dam section in front of the Auxiliary Building rollup door."	X										
Grand Gulf	"The licensee did identify temporary manual actions in its walkdown report that would be implemented in the event of a flood threat. That temporary manual action	X										

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
	included the placement of sandbags at the 11 designated PMP doors.”												
Hope Creek	“There are no temporary flood protection features credited in the HCGS CLB. Manual actions requiring [personnel] action are triggered when the water level of the Delaware River reaches 95.0 ft. PSD at the SSWS intake structure. These include: • Closing all SSWS intake structure watertight perimeter flood doors within 1 hour, or declare affected service water system components inoperable and take other required actions; • Closing all power block watertight perimeter flood doors within 1.5 hours. The facility will be in at least hot shutdown within the following 12 hours and in cold shutdown within the following 24 hours. Once closed, all access through the doors is administratively controlled.			X								
Indian Point	“In addition to permanent barriers, the units have temporary barriers and other manual actions that require [personnel] actions. The temporary flood protection features include portable gas-powered pumps, submersible electric pumps and sandbags, among other actions. Manual actions would be implemented to protect the Service Water Strainer Pit at the Intake Structure to assist the strainer pit sump pump. The manual actions associated with these procedural activities include the placement of	X				X						

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
	sandbags around the strainer pit and the movement and staging of a temporary portable pump.											
Monticello	"The licensee stated that the site has temporary barriers and manual actions requiring [personnel] involvement, including installation of steel plates; construction of levees; deployment of sandbags; construction of berms; maintaining diesel oil storage levels; and weighting of floors to resist buoyant forces. When the water surface elevation in the river is predicted to exceed 930 feet MSL, a levee is constructed to protect the Class I structures, Class II structures that contain Class I equipment, and the radwaste building. The offgas stack, also a Class I structure, is outside the levee perimeter and would be protected using sandbags. The offgas storage building is a Class II structure containing Class I equipment; however, all of the Class I equipment and components inside the building are located above the peak DBF water surface elevation. The licensee stated that other temporary flood protection features such as steel plates, grouts, or sandbags may be used to provide additional defense in depth when the river water surface elevation is expected to exceed 930 feet MSL. Protection for the diesel generator building is provided by either constructing a flood barrier around the building or by preventing the buckling of the floor slab of the building. Buckling prevention is provided up to a flood water surface elevation of 933 feet MSL by exposing the entire floor area to a loading of 200 psf. If	X	X				X					

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Monticello	the flood water surface elevation is expected to exceed 933 feet MSL, a flood barrier would be constructed around the diesel generator building. The licensee stated that the emergency diesel oil storage tank is designed for a floodwater surface elevation of 932 feet MSL, with a minimum of 2 feet of fuel oil maintained in the tank. For flood water surface elevation exceeding 932 feet MSL, the tank would be protected by a flood barrier or by a berm constructed around the tank.”											
North Anna	“The licensee reported that the site has temporary barriers and other manual actions that require [personnel] action. The actions include: 1) implementation of the Corporate Hurricane Response Plan when the projected onsite arrival of hurricane force wind is greater than 36 hours away; 2) activating the emergency plan when onsite wind speed is greater than or equal to 80 mph; and, 3) initiating the Abnormal Procedures 0-AP-40 and 0-AP-41 under severe weather conditions or flooding events. The licensee stated that the Abnormal Procedure 0-AP-40 includes taking mitigation actions when the lake level reaches 251 ft. MSL, closing the drain pipe valve when the lake level reaches 252 ft. MSL to prevent lake inflow from the west dike drain pipe due to a rising lake level, and manually shutting down both units and closing the circulation water valves to prevent flooding of the turbine building through the		X		X							X

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	**Manual Actions**	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… North Anna	circulating water system when the lake level reaches 254 ft. MSL. The licensee stated that the Abnormal Procedure 0-AP-41 include reviewing weather bulletins; closing, replacing, or installing temporary measures for manholes, blocks, and missile barriers; monitoring the intake structure for debris; and evaluating the weather-related risks associated with suspended processes such as maintenance and fuel handling.”											
Peach Bottom	“The licensee stated that the PBAPS site has flood protection features consisting of temporary barriers and features that require manual action. The actions include: • protecting the Emergency Pump Structure, • confirming that watertight doors are closed and secure, • sealing a Turbine Building drain that flows to the Radwaste Building, • opening the Turbine Building sump pump breakers to protect the Radwaste Building from flood waters, • preventing backflow from the Diesel Generator Building sump overflow drain, • and activating the Emergency Cooling Water System. Action on each feature is dependent on exceedance of a river surface water level trigger with response preparation initiated when river surface water levels are at or above 109.5 ft CD per PBAPS Procedure AO 28.2.		X	X	X				X	X		

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Point Beach	"The site has temporary barriers and manual actions requiring [personnel] involvement. The temporary barriers include jersey barriers on the north and south sides of the CWPH that provide protection up to +9 feet, designed to protect equipment in the CWPH, the turbine buildings, and the control building. Installation of these barriers requires manual action prompted by site procedure. Construction of the barriers commences if a monthly check of Lake Michigan water level reveals a value of 580.7 feet IGLD or higher. The licensee reports that the barriers will protect the plant from up to +9 feet of water. Construction of the barriers requires an undisturbed lake level, but because lake levels do not change quickly the licensee is confident that inclement weather could not prevent installation of barriers within the required time. The barriers can be installed within three weeks and are taken down only when the monthly check reveals a water level below 580.7 feet."	X	X									
Prairie Island	The actions and/or associated barriers include: • flood doors and bulkheads • portable pumps • and enactment of plant flood operating procedures.		X	X		X						
Quad Cities	The QCNPS site has no temporary flood protection barriers. The response to a potential design-basis flood is to implement its flood emergency procedure that includes the following manual actions:					X	X	X	X	X		

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Quad Cities	• Enter the flood emergency procedure based either on observed river levels (586 ft MSL) or levels predicted to occur within 72 hours (594 ft MSL); • Place the mobile make-up demineralizer system into operation to fill existing water storage tanks and to provide additional water as required; • Move and stage a portable, gasoline-fueled pump (i.e., the "Darley pump") to provide make-up water for the water evaporated from the reactors and spent fuel storage pools throughout the duration of the flood; • Implement normal shutdown of both reactor units; • Initiate and complete the disassembly of both reactor units; • Add water to tori/drywells; • Fill reactor cavities and dryer-separator pools with water; • Fill radwaste tanks with water; • De-energize station loads; • Place drywell loads in pull-to-lock status; • Seal the diesel oil storage tank vents; and Open plant doors to permit the free flow of flood waters.											
Salem	"Manual actions requiring [personnel] action are initiated in the event of a major storm per plant procedures including "Severe Weather and Natural Disaster Guidelines," and "Adverse Environmental Conditions," as well as the SGS Technical			X		X				X		X

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Salem	Specifications. Additional procedures provide planning and preparation for potential flooding events, depending on site conditions. These include: • Review out-of-service equipment (e.g., sump pumps) to prioritize restoration efforts; • Ensure the Material Center has adequate sump pumps totaling 2,000 gallons per minute; • Ensure that adequate water removal pumps, hoses, drain pipes, etc. are available and pre-staged at the Material Center; • Verify operability of intake structure sump pumps; • Review plant work activities having breaches that could cause flooding in the plant due to flood tides; • Initiate a notification to inspect the shoreline protection and dike system; • Consider implementation of other procedures (e.g., "Adverse Environmental Conditions"); • Verify the closure of all watertight doors, as required; • Consider maximizing room in the Waste Holdup Tanks to support potential water intrusion into the Auxiliary Building. The "Adverse Environmental Conditions" procedure ensures compliance with required actions such as evaluating the need for sump pumps, closing and securing all watertight doors, monitoring and recording river level until it has stabilized, and commencing shutdown procedures."											

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Sequoyah	"The walkdown report describes the actions to be taken during flood preparation, including the relocation of supplies needed for implementing the flood protection plan above the DBF level. Temporary piping connections would be made to switch plant cooling loads from the component cooling water (CCW) system to the ERCW system. • Onsite power supply loads would be adjusted. • Power and communication lines below the DBF not designed for submerged operation would be disconnected. • The wall penetration for drainage from the ERCW deck would be sealed if necessary. • If flood preparation were to occur during refueling, actions would depend on the stage of refueling and the available warning time. The spent fuel pool cooling and cleanup system heat exchanger output flow would require a temporary piping (spool piece) to connect it to the residual heat removal system heat exchanger bypass line.				X			X	X		X	
South Texas Project	"Active barriers that require [personnel] action include two doors per unit that are normally open and do not have status indicators. Station "security personnel are assigned the duty to close these doors in the event of a flooding event."			X								

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
St. Lucie	The licensee stated that it has temporary barriers and other manual actions at the site that require [personnel] action. The actions/barriers include installing stoplogs at the south side of the Unit 2 Reactor Auxiliary Building.		X									
Surry	"The actions/barriers include the Emergency Service Water Pump House (ESPH) temporary barriers that are manually installed according to established procedures prior to the arrival of a hurricane. These barriers include: • manually installed covers on air intake louvers; • manually installed seal plates and exterior covers on ESPH doors and intake louver openings; • and manually installed flood gate on the ESPH doors."		X					X				
Three Mile Island	"The licensee reported that the TMI site has flood protection features consisting of temporary barriers and features that require manual action. These actions include: • Closing missile shield doors and inflating door seals at the Fuel Handling Building. • Flood gates will be installed at various locations around the plant including the Intake Screen Pump House (ISPH) where a hatch, drain seals and sump pumps are installed. The hatch prevents flood water from entering through the flood protection boundary		X	X	X					X		

Manual Actions from NRC Flooding Walkdown Staff Assessments													
		Performed (or partially) Outside a Facility							Performed Inside a Facility				
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Three Mile Island	while the sump pumps remove water that may leak past the external flood boundary. • Floor drain plugs are installed in the Turbine Building and the personnel hatch area of the Reactor Building. The flood emergency procedure (OP-TM-AOP-002) is initiated for any of the following conditions: The Susquehanna River level at ISPH exceeds 284.2 ft (200,000 cfs); Susquehanna River level at the NWS Harrisburg Gage exceeds 12.63 ft {200,000 cfs); or, NWS Forecast Center forecasts a Susquehanna River flow greater than 350,000 cfs within the next 36 hours."											
Turkey Point	"The licensee stated that the site has temporary barriers, flood-mitigation equipment, and other actions that require [personnel] action. TPNG operating procedures include a hurricane season readiness procedure that outlines actions to be taken within 72 hours of a hurricane arrival. The licensee credits these actions as part of the flood protection system. The actions include: • Installation of portable dewatering pumps and associated equipment, • Installation of the drain plugs in the plant, • Installation of stoplogs at exterior door openings, and • Construction of sandbag dikes at specific doors, drains, and manhole covers, including filling of sandbags.	X	X	X	X	X						

Manual Actions from NRC Flooding Walkdown Staff Assessments

Site	Manual Actions	Performed (or partially) Outside a Facility							Performed Inside a Facility			
		Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Continued… Turkey Point	The licensee inspected the physical condition of the temporary equipment to determine that the equipment functions could be performed. The licensee inspected storage locations to determine the accessibility of equipment and whether storage was appropriate (i.e., above flood elevation).”											
TOTAL	*Plants with reported manual actions*	11	19	12	9	8	3	3	5	6	3	5
Braidwood	No temporary barriers and no procedures or actions requiring manual or operation in case of flooding.	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Byron	“The site has no temporary barriers and other manual actions that require [personnel] action in the event of a flood threat.”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Callaway	“The site has no temporary barriers that require manual [personnel] actions in the event of a flood threat.”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Calvert Cliffs	“The licensee did not identify any temporary barriers and other manual actions that require [personnel] action in the event of a flood threat in the walkdown report.”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Columbia	“The site has no temporary barriers or manual actions required per the CLB.”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Comanche Peak	“The licensee stated that the site has no temporary barriers and other manual actions that require [personnel] action in the event of a flood threat.”	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Davis-Besse	The licensee reported that the site requires no temporary barriers or equipment that requires [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
DC Cook	"The licensee stated that the site has no temporary barriers or other manual actions that require [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hatch	"The licensee reported that the site does not have manual actions such as sump pumps, portable pumps, or isolation and check valves that require [personnel] action. Provisions for a temporary sandbagging barrier existed in the HNP site's procedure 34AB-Y22-002-0, but a simulation by the licensee revealed that sandbagging was not needed and was subsequently removed from the operating procedure as discussed in Section 3.2.4."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fermi	The licensee stated that the site has no credited temporary barriers [or manual actions].	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FitzPatrick	"The licensee reported that the site does not have temporary barriers and other manual actions requiring [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Farley	"The licensee stated that FNP does not rely upon active or temporary features for protection."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LaSalle	" The licensee stated that LSCS does not rely upon active or temporary features for protection."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Limerick	"The licensee stated that LGS does not rely upon temporary features for protection. The licensee notes sandbags would be installed to prevent water damage,	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Manual Actions from NRC Flooding Walkdown Staff Assessments

		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	**Manual Actions**	**Deploy Sandbags, Build Berms**	**Place Flood Barriers**	**Close Doors/ Gates/ Hatches/ Manhole Covers**	**Plug Drains/ Close Valves/ Seal Openings**	**Install and Operate Portable Pump/ Sump**	**Equalize Pressure (Open doors, weigh floor)**	**Seal Fuel Vents and Cover Air Intakes**	**De-energize/ Adjust Electrical Power**	**Operate Installed Plant Sumps/ Pumps**	**Connect Piping Spool/ electrical jumpers**	**Monitor Leakage/ Hazard/ Weather/ Debris**
	if time permits. However, sandbag installation is not required to maintain the plant in a safe condition."											
McGuire	"The licensee stated that the MNS site does not have temporary barriers and other manual actions requiring [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Millstone	"The site has neither temporary barriers nor other manual actions that require [personnel] action. The licensee did not describe any temporary barriers for flood mitigation or protection."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nine Mile Point	"The NMP site does not have temporary barriers and other manual actions requiring [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oconee	"The licensee reported that the site has temporary barriers and other manual actions that require [personnel] action. Note that the previous walkdown in early 2012 was credited for certain manual actions including the sandbags."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oyster Creek	"The licensee indicated that the site has no temporary barriers or manual actions that require [personnel] action that are credited for flood protection and committed to in the CLB."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Palisades	"The licensee stated that the site has no temporary barriers nor manual actions that require [personnel] action. The watertight doors in the Turbine Building and Auxiliary Building are considered incorporated active barriers, however are normally closed therefore do not require manual actions."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Palo Verde	"The site has no temporary barriers that require manual [personnel] actions in the event of a flood threat."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Perry	"The licensee stated that the flood protection features are barriers that are either passive or active mechanical systems that do not require any operation action to perform their design function, thus no [personnel] actions are credited in the CLB."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pilgrim	"The licensee stated that Pilgrim has no temporary barriers and other manual actions that require [personnel] action for the CLB storm surge event."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Robinson	The staff assessment letter indicated that the material was "sensitive unclassified information" and no report was attached.											
Seabrook	"The licensee stated that the site has neither temporary barriers nor manual actions requiring [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Shearon Harris	"The licensee did not identify any temporary barriers and other manual actions in its Walkdown Report that require manual [personnel] action in the event of a flood threat."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Summer	"The licensee's walkdown report indicates there are no flood mitigation features credited in the CLB. In addition, there are no plant procedures requiring actions in the VCSNS CLB that provide for flood protection or mitigation."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Manual Actions from NRC Flooding Walkdown Staff Assessments												
		Performed (or partially) Outside a Facility							Performed Inside a Facility			
Site	Manual Actions	Deploy Sandbags, Build Berms	Place Flood Barriers	Close Doors/ Gates/ Hatches/ Manhole Covers	Plug Drains/ Close Valves/ Seal Openings	Install and Operate Portable Pump/ Sump	Equalize Pressure (Open doors, weigh floor)	Seal Fuel Vents and Cover Air Intakes	De-energize/ Adjust Electrical Power	Operate Installed Plant Sumps/ Pumps	Connect Piping Spool/ electrical jumpers	Monitor Leakage/ Hazard/ Weather/ Debris
Susquehanna	"The licensee reported that the site has no temporary barriers or other manual actions that require [personnel] action in the event of flooding; however, in the CLB, normally closed external flood doors at the Control Structure and at the Reactor Buildings (both at 676 ft MSL) are credited with protecting SSCs during a rupture of the cooling tower basin."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vogtle	"The licensee reported that the site has no temporary barriers or other manual actions that require [personnel] action."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Wolf Creek	"The site has no temporary barriers that require manual [personnel] actions in the event of a flood threat."	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

APPENDIX B
MANUAL ACTIONS FOR A NUCLEAR POWER PLANT

B.1 Background

In one of the NRC's flood walkdown staff assessments, the staff stated that "[t]he licensee stated that the site has temporary barriers and manual actions requiring personnel involvement, including installation of steel plates; construction of levees; deployment of sandbags; construction of berms; maintaining diesel oil storage levels; and weighting of floors to resist buoyant forces." The flood walkdown staff assessment contains additional description regarding when and where activity associated with building berms and levees should be started, but no further description of the manual actions.

A detailed External Flooding Instruction Procedure for a plant is summarized and excerpted below.

B.2 Summary of Tasks

The reviewed External Flooding Instruction Procedure included 106 tasks. These tasks were grouped below in Table B-1 based on the manual actions (MAs), as listed in section 3.3, and supplemented with actions to obtain fuel or recipient and relocated or stage equipment.

Table B.1 Summary of tasks in an example External Flooding Instruction Procedure

Number of Tasks	Description
MAs that may be entirely or partially performed outside a facility	
27	Deploy sandbags and build berms[1]
1	Place flood barriers
7	Close doors, gates, hatches, and manhole covers
23	Secure drains, close valves, and seal openings
2	Set up and operate portable pump and sumps
4	Equalize pressure (open doors, weight floor)
7	Seal fuel vents and cover air intakes
3	Monitor leakage, hazards, weather, and debris
MAs performed inside a facility	
5	De-energize and adjust electrical power
1	Operate installed plant sump or pump systems
3	Connect piping spool to alternate cooling source
Other MAs	
8	obtain fuel or supplies
15	relocate equipment supplies

[1] Two of the tasks involve constructing "berms" or "levees" of substantial size, while many deploy sandbag tasks may only refer to sandbagging a doorway

B.3 Excerpts from a Nuclear Power Plant's External Flooding Instruction Procedure

The following are excerpts from the 106 tasks listed. Specifics have been anonymized and references to established procedures, handbooks, drawings and standards removed.

Excerpt 1

- Construct a sandbag barrier, levee, or berm around the [building] up to [certain] elevation.
- Remove fire hoses and equipment from all grade-level hose [building] in the [certain] areas.
- Temporary (diesel) storage tanks or tankers should be brought onsite…
- If the access road is flooded, use boats or helicopters to bring fuel onto the site and replenish the temporary tanks or tankers.
- Take the traveling screens off "AUTO" and station personnel in continuous attendance at the traveling screens. Open the side inspection doors and dispose of trash manually since trash may not properly sluice away.

Excerpt 2

- Position the hatch cover(s) next to the openings so that they can be rapidly attached.
- Station a watch person to monitor water level.
- If for some reason the [certain] level begins to rise uncontrollably, discontinue pumping and secure hatch cover(s).
- Locate and rent additional electric or gas-driven sump pumps for unexpected groundwater in-leakage…
- When [certain] piping temperatures have dropped to < [a temperature], fill the [certain] tank with water.
- Secure the screen wash system pumps. De-energize all electrical circuits to the Screen House. From this point on, the screens must be jogged and cleaned manually (if possible) …
- Remove the drive motor from the trash rake and install a handcrank for traversing the rake.

Excerpt 3

- Remove the following as required: security fence sections, protected fence sections.
- Scarify or rip concrete and asphalt surfaces under levee. This will provide lateral support against hydraulic forces as well as to provide a barrier to leakage.
- Stop storm sewer system. Install heavy duty flex plug [locations]. Install lateral bracing and backup blocking between plug and manhole sidewall.
- Obtain [a length of a size] diameter culvert or any other thin wall pipe for installation in the I.D. of yard storm drains and manholes. The pipe/culvert sections are to be blocked in vertically and extend up to [a certain elevation]. Seal gaps between the pipe/culvert and I.D. of drain or manhole with polyethylene sheet. Then sandbag around the culverts to hold them in place and backfill if located in the path of the earth levee.
- Duct seal all conduits that communicate across the levee section. Install duct seal from waterside of conduit whenever possible.

Excerpt 4

- Relocate essential fire brigade equipment to the [a certain room].
- Install a steel plate at opening for [a certain door].
- Install steel plates on the outside [certain] walls of the [a certain building].
- Construct a sandbag barrier around the [certain building] shown up to [a certain] elevation.
- Remove the[certain] plug on the [certain building]. Sandbag periphery of the [certain building] plug opening up to [a certain] elevation.

Excerpt 5

- Sandbag [a certain door].
- Sandbag [a certain door].
- Ensure electrical conduit and pipe penetrations through [a certain building] exterior walls are closed up with steel plate or sealed with grout to [a certain] elevation.
- Cap the [certain building] drain. Also verify the [certain] drain valves to the [certain container] on [certain] elevation are closed.
- Plug all floor and equipment drains in the [certain room].
- Sandbag [a certain door].
- Install steel plate over [a certain door].

Excerpt 6

- Sandbag [a certain door].
- Sandbag [a certain door].
- Sandbag [a certain door].
- Sandbag [a certain door].
- Sandbag [a certain door].

APPENDIX C
REVIEWED HUMAN PERFORMANCE LITERATURE

The research team compiled and reviewed a large set of human performance literature pertinent to evaluation of the effects of environmental conditions. A list of this literature set is available as an electronic table from the U.S. Nuclear Regulatory Commission.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1992	29 CFR 1910 §1910.95. N.D. "General Industry Regulations, Subpart G Occupational Health & Environmental Control, Occupational Noise Exposure." Occupational Safety and Health Administration, US Dept. of Labor, Washington, DC. Available at https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10116.	CFR occupational noise regulations as of 1992.	Useful for setting exposure limits
2009	Abrahamsen, B., T. van Staa, R. Ariely, M. Olson and C. Cooper. 2009. "Excess Mortality Following Hip Fracture: A Systematic Epidemiological Review." Osteoporosis International 20(10):1633-1650.	Outlines effects of Ice/Snow and related slipping on injuries and mortality	Provides data on ice slip rates and mortality in older adults
1989	Abt, S.R., R.J. Wittler, A. Taylor, and D.J. Love. 1989. "Human Stability in a High Flood Hazard Zone." *Water Resources Bulletin* 25(4):881-890.	A series of human subjects were tested to determine the velocity and depth of flow that caused their instability. A relationship was developed to estimate the product of the velocity and depth at toppling at which a human subject becomes unstable as a function of the height and weight of the subject.	Model for human instability in flood water
2006	ACGIH (American Conference of Governmental and Industrial Hygienists). 2006. Noise: TLV® Physical Agents 7th Edition Documentation, Cincinnati, OH.		Provides threshold limit values for noise.
2012	Agdas, D., G.D. Webster, and F.J. Masters. 2012. "Wind Speed Perception and Risk." *PloS one* 7(11):e49944. http://journals.plos.org/plosone/article/asset?id=10.1371%2Fjournal.pone.0049944.PDF.	Wind and risk perception - people were accurate at lower wind speeds but overestimated wind speeds at higher levels. Wind speed perceptions mediated the direct relationship between actual wind speeds and perceptions of risk (i.e., the greater the perceived wind speed, the greater the perceived risk). The number of tropical cyclones people had experienced moderated the strength of the actual–perceived wind speed relationship; consequently, mediation was stronger for people who had experienced fewer storms.	Risk perception assoc with fear - takes up cog processing resources and could affect multiple perf reqs
2012	Alfano, F. R.D., B.I. Palella, and G. Riccio. 2012. "On the Problems Related to Natural Wet Bulb Temperature Indirect Evaluation for the Assessment of Hot Thermal Environments by Means of WBGT."	This paper deals with the indirect evaluation of the natural wet bulb temperature, t nw, one of the two quantities forming the basis of the well-known wet bulb globe temperature (WBGT) index, considered worldwide to be a suitable and user-friendly tool for the preliminary assessment of hot thermal environments. This quantity can be measured by a wet bulb thermometer (a temperature sensor covered with a wetted wick naturally ventilated) or, if this is not available, calculated from other microclimatic parameters (i.e. the air temperature, the globe temperature, the air velocity, and the humidity) using a quite trivial energy balance equation. Because of the strong non-linear structure of such an equation, the risk of a multiplicity of steady state solutions could result in the failure to obtain a reliable index evaluation. To dispel all doubts, this work carries out an in-depth analysis of the heat balance equation to be solved for the indirect evaluation of the natural wet bulb temperature. A preliminary investigation of each heat flow term involved in the heat balance on the sensor has been carried out; in a second phase a special continuation method has been implemented, highlighting the effect of microclimatic parameters on the multiplicity of solutions. Results show that under free convection the evaluation produces a single solution only under uniform conditions, whereas in the presence of even slight differences between the air temperature and the mean radiant temperature, there can be as many as three solutions. This phenomenon, if confirmed by a further experimental investigation, could become a difficult matter since a sensor, in principle, has to read a unique value of the quantity measured. In any case, from a numerical point of view, the presence of many values of t nw greatly reduces the possibility of an indirect WBGT calculation from the other involved physical quantities; as a consequence, the indirect evaluation of WBGT should be clearly avoided based on ISO 7243 Standard.	One of the several detractors to aspects of currently most popular heat metric: WGBT
2016	Alkozei, A., R. Smith, D.A. Pisner, J.R. Vanuk, S.M. Berryhill, A. Fridman, B.R. Shane, S.A. Knight, and W.D. Killgore. 2016. Exposure to Blue Light Increases Subsequent Functional Activation of the Prefrontal Cortex During Performance of a Working Memory Task. Sleep, Cognition & Behavior, 39(9):1671–1680.	Blue light exposure improves working memory task performance	Lighting characteristics (blue in particular) can affect higher cognition
1974	Allan, J. R., P. Marcus and C. Saxton. 1974. "Effect of Cold Hands on an Emergency Egress Procedure." Aerospace Medicine 45(5):479-481.	Egress speed with cold hands - The results show that egress times will increase from practiced control levels (+10°C) after about 5 min in an environment of -30°C, 8 min in -20°C, and 14 min in -10°C. Egress time is doubled after 14, 37 and 57 min respectively in the same conditions. The experiments also showed that the duration of cold exposure had important effects on egress performance by an effect other than the lowering of finger surface temperature, which suggests that the cooling of other	Effects of cold skin on fine motor perf
2000	Allender, L. 2000. "Tools for Modeling Human Performance in Systems through Green-Colored Glasses: An Army Perspective." in Proceedings of the XIVth Triennial Congress of the International Ergonomics Association and 44th Annual Meeting of the Human Factors and Ergonomics Association, 'Ergonomics for the New Millennium', July 29, 2000 - August 4, 2000, pp. 717- 720.	IMPRINT enables a quantitative portrayal of human performance. Task network modeling is implemented with embedded data and sound psychological methods in an easy-to-use interface, all of which has been subjected to intensive verification and validation. IMPRINT is being used today to influence system design and acquisition decisions. Several examples of applications to Army systems are discussed, with implications ranging from detailed equipment design to force-on-force effectiveness. Of course, "more research needs to be done," but in the meantime, human performance modeling is ready for use.	IMPRINT models effects of different ECs on task performance

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2000	Allender, L. Modeling Human Performance: Impacting System Design, Performance, And Cost. In M. Chinni (ed.) Proceedings of the Military, Government and Aerospace Simulation Symposium, 2000 Advanced Simulation Technologies Conference (Washington, D.C.) 139-144.	Human performance must be modeled, and modeled early in order to impact system design, performance, and cost. The underlying rationale and examples of such modeling are discussed. A key reason that human performance must be modeled is that the human component is probably the "noisiest" component in the system. The examples given here are all based on models developed with the capabilities present in IMPRINT (the Improved Performance Research Integration Tool), developed by the Human Research and Engineering Directorate of the U.S. Army Research Laboratory.	IMPRINT background rationale
2005	Allender, L., T. Kelley, S. Archer, and J. Lockett. 2005. "Human Performance Modeling in the Army: A Long and Winding Road." in 49th Annual Meeting of the Human Factors and Ergonomics Society, HFES 2005, September 26, 2005 - September 30, 2005, pp. 1191-1195. Human Factors an Ergonomics Society Inc., Orlando, FL, United states	Human performance must be modeled early to impact system design, cost and performance.	Reason is that humans are a key cog in the role of a system.
1995	Allender, L., T.D. Kelley, L. Salvi, J. Lockett, D.B. Headley, D. Promisel, D. Mitchell, C. Richer, and T. Feng. 1995. "Verification, Validation, and Accreditation of a Soldier-System Modeling Tool." in Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol 39, pp. 1219-1223.	IMPRINT Tool validation paper	IMPRINT background rationale
2005	Alley, T. 2005. Directory of Design Support Methods. DTIC Document.	This Directory contains references to human systems integration (HSI) design and interface tools, techniques, databases, guides and standardization documents. HSI encompasses human factors, human performance, training, manpower and personnel systems analysis and design. Contributors include: U.S. Department of Defense (DoD), Federal Aviation Administration (FAA), National Aeronautical and Space Administration (NASA), other U.S. government agencies, NATO countries, academia, and private industry.	Review/background paper with HF approach rationale
2014	Amrein, B.E., et al. 2014. *Sensory Perception in the Human Research and Engineering Directorate: Thrust Areas and Recent Research 2011–2014.* ARL-SR-0293, Army Research Laboratory, Aberdeen Proving Ground, Maryland.	This report provides an overview of ARL/HRED's sensory perception research during 2011–2014. The goal of this research is to understand the perceptual requirements of interpreting unaided and aided visual, auditory, and tactile signals in complex, dynamic, militarily relevant environments.	Degradation in cognitive performance related to extreme environmental stressors
2015	AMS (American Meteorological Society). 2012. Glossary of Meteorology. Meteorology Glossary American Meteorological Society. Accessed 4 June, 2016. Available at http://glossary.ametsoc.org/wiki/Main_Page (last updated 28 July 2015).	Online searchable glossary of meteorological terms.	Provides accepted definitions for meteorological terms. See also NOAA 2009 National Weather Service glossary.
2012	Andersen, T. B., Bentzen, J., Dalgaard, C. J., & Selaya, P. (2012). Lightning, it diffusion, and economic growth across us states. Review of Economics and Statistics, 94(4), 903-924.	Abstract—Empirically, a higher frequency of lightning strikes is associated with slower growth in labor productivity across the 48 contiguous U.S. states after 1990; before 1990, there is no correlation between growth and lightning. Other climate variables (e.g., temperature, rainfall, and tornadoes) do not conform to this pattern. A viable explanation is that lightning influences IT diffusion. By causing voltage spikes and dips, a higher frequency of ground strikes leads to damaged digital equipment and thus higher IT user costs. Accordingly, the flash density (strikes per square kilometer per year) should adversely affect the speed of IT diffusion. We find that lightning indeed seems to have slowed IT diffusion, conditional on standard controls. Hence, an increasing macroeconomic sensitivity to lightning may be due to the increasing importance of digital technologies for the growth process.	Economic growth is inversely related to the frequency of lightning across states
1998	Andrey. J. and S. Yagar. 1993. "A Temporal Analysis of Rain-Related Crash Risk." *Accident Analysis & Prevention* 25(4):465-472.	The study presents empirical evidence of accident risk during and following rain events in the cities of Calgary and Edmonton, Canada. The matched sample approach is used to examine data for 169 rain events and over 15,000 accidents that occurred during the years 1979–1983. The overall accident risk during rainfall conditions was found to be 70% higher than normal. The data suggest that accident risk returns to normal as soon as the rainfall has ended, despite the lingering effects of wet road conditions.	Effects of rain on driving performance (continuous/discrete fine motor)
2001	Archer, S., and L. Allender. 2001. "New Capabilities in the Army's Human Performance Modeling Tool." Simulation series. 3322-27.	IMPRINT background	
2010	Armstrong, L.E., E.C. Johnson, D.J. Casa, M.S. Ganio, B.P. McDermott, L.M. Yamamoto, et al. 2010. "The American Football Uniform: Uncompensable Heat Stress and Hyperthermic Exhaustion. *Journal of Athletic Training* 45:117-127	Evaluated different effects of 2 American football uniforms on heat exhaustion	Heat effects on exhaustion (collapse) associated with protective clothing.

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2002	Armstrong. L. E. and J. Stoppani. 2002. "Central Nervous System Control of Heat Acclimation Adaptations: An Emerging Paradigm." http://dx.doi.org/10.1515/REVNEURO.2002.13.3.271.	The role of the central nervous system (CNS) in the control of human heat acclimation (HA) and HA adaptations at the ultrastructural and biochemical level are not well described, although empirical evidence demonstrates that the hypothalamus adjusts thermoregulation subsequent to 8-14 days of exercise in a hot environment. Therefore, numerous investigations and concepts are presented in this paper that 1) describe plausible mechanisms for the development and CNS control of physiological adaptations and enhanced performance during heat acclimation, 2) include adaptations of neuron morphology and biochemical pathways, 3) account for situations in which homeostatic control during exercise in heat is inadequate, and 4) describe applications to other phenomena in physiology and medicine. The resulting paradigm incorporates information storage, temperature-sensitive neurons in the brain, and neural plasticity.	Within certain limits, 7 to 14 days of consistent but controlled exposure to heat prompts the body to adapt so that homeostatic mechanisms are better able to maintain homeostasis.
2004	ASCE (American Society of Civil Engineers). 2004. "Outdoor Human Comfort and Its Assessment: State of the Art." Task Committee on Outdoor Human Comfort, American Society of Civil Engineers, Reston, VA	This report describes state-of-the-art methods for assessing and improving outdoor human comfort. Factors affecting outdoor comfort are wind, air temperature, humidity, sun, and precipitation. Wind, in particular, is greatly affected by large buildings, and many modern developments are wind-tunnel tested to examine how wind flows around new buildings will affect pedestrians.	Provides insight into the mechanical effects of wind of different speeds on the human body (see Table 6.8-1).
2015	Ashley, C.D., J. Ferron, and T.E. Bernard. 2015. "Loss of Heat Acclimation and Time to Re-Establish Acclimation." *J Occup Environ Hyg* 00-00. http://dx.doi.org/10.1080/15459624.2014.987387.	The purpose of this study was to determine the rate of loss of heat acclimation over a period of 6 weeks and determine the time needed for re-acclimation after 2 weeks and 4 weeks of de-acclimation in ten healthy participants.	Performance degradation due to heat stress, and loss of heat acclimatization
2009	ASME (American Society of Mechanical Engineers). 2009. *Addenda to ASME/ANS-RA-S-2008 Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications.* ASME/ANS RA-Sa-2009, New York, New York.	Level 1/Large Early Release Frequency PRA standard for commercial light-water reactor NPPs.	Background for PRA
1974	Baddeley, A. D. and G. J. Hitch. 1974. *Working Memory.* ed: G. A. Bower, The Psychology of Learning and Motivation, Academic Press, New York, NY. 47-89.	Analyzes current major trends in memory research, considering their historical significance and importance outside the laboratory	Classical model of how speech noise affects the working memory process for verbal tasks by competing for limited resources in the phonological loop
1975	Baddeley, A., W.J. Cuccaro, G.H. Egstrom, M.A. Willis, G. Weltman. 1975. "Cognitive Efficiency of Divers Working in Cold Water." *Human Factors* 17(5):446-54	Summarizes Baddeley's classic context dependent learning effect.	Cold water exposure effects on cognition
2000	Baddeley, A.D. 2000. "Selective Attention and Performance in Dangerous Environments." *Journal of Human Performance in Extreme Environments* 5(1):	Evidence on human performance in dangerous environments is reviewed and suggests that danger reduces efficiency, except in the case of experienced subjects.	Performance degradation in perceived dangerous environments
1991	Badia, P., B. Myers, M. Boecker, J. Culpepper and J. R. Harsh. 1991. "Bright Light Effects on Body Temperature, Alertness, Eeg and Behavior." *Physiology & Behavior* 50(3):583-588.	Photic stimulation during daytime and nighttime hours and its effects on physiology, sleepiness, alertness, and other task performance	Effects of Light during day/night on performance
2009	Bagnall, T., and K. Hart. 2009. *Air Force Human Systems Integration Improved Performance Research Integration Tool (Imprint Pro) Maintenance Model Enhancements.* Alion Science and Technology, Boulder, CO. http://www.dtic.mil/dtic/tr/fulltext/u2/a558299.pdf	Discusses model enhancements for IMPRINT	IMPRINT background rationale
2015	Baker, C. 2015. Risk analysis of pedestrian and vehicle safety in windy environments. J. Wind Eng. Ind. Aerodyn. 147:283–290.	This paper presents a risk analysis for assessing the risk of such incidents that unifies current rather disparate methodologies, and presents a novel and consistent risk based framework for the assessment of future building developments. The paper first discusses the nature of current methodologies, and argues that methods that are based on the probability distribution of wind velocities alone are not wholly adequate. The new methodology takes the wind velocity probability distribution functions that can be obtained from wind tunnel measurements and convolutes these with the cumulative distribution functions for human and vehicle instability in high winds to give a risk of an accident occurring and the consequences of the calculated risk. It is argued that such a risk based methodology allows for greater consistency in the application of any pedestrian/vehicle movement restrictions or alleviation methods. Finally other potential applications and extensions of the method are discussed – Specifically the application of the proposed methodology to wind comfort studies and also to the problem of passenger instability caused by the slipstreams of trains.	Baker (2015) offers an alternative, but not time-tested, risk-based analysis approach to pedestrian and vehicle safety in windy environments.

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1986	Banderet, L.E., B.L. Shukitt, E.A. Crohn, R.L. Burse, D.E. Roberts, and A. Cymerman. 1986. *Effects of Various Environmental Stressors on Cognitive Performance.* U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts.	This paper presents findings and illustrates methodology for evaluating the effects of several types of environmental stressors on cognitive performance.	Impact of environmental stressors on cognitive performance
1988	Barnston, A. G. 1988. The Effect of Weather on Mood, Productivity, and Frequency of Emotional Crisis in a Temperate Continental Climate. International Journal of Biometeorology 32:134-143.	The weather appears to influence mood and productivity, but only to a small extent compared with the aggregate of all other controlling factors. Males show a relatively stronger effect than females. Psychologically troubled people generally appear to be more affected by weather than university students. The students and the crisis intervention service clients with "mild" problems tend to be stressed more when the weather is unstable, cloudy, warm and humid, and least stressed during sunny, dry, cool weather with rising barometric pressure. The crisis service clients with "severe" problems react oppositely to these two weather types.	Rain, humidity effects on mood and productivity - possibly relevant to performance effects.
1990	Baron, S., D.S. Kruser, and B.M. Huey. 1990. Quantitative Modeling of Human Performance in Complex, Dynamic Systems. National Academies Press,	Book describing various approaches to modeling of human behavior	General usefulness in supporting the modeling approaches advocated in the paper.
1996	Baughman, A., and E. Arens. 1996. Indoor Humidity and Human Health — Part I: Literature Review of Health Effects of Humidity-Influenced Indoor Pollutants. *ASHRAE Transactions* 102(1):193-211.	Summary of findings regarding humidity's effects on presence of airborne contaminants.	Humidity effects on Also discusses ASHRAE standards for humidity.
2013	Beaven, C. M. and J.A. Ekström. 2013. Comparison of blue light and caffeine effects on cognitive function and alertness in humans. PLoS One 8:1-7, e76707.	Study comparing caffeine and blue light exposure effects on performance. Both the caffeine only and blue light only conditions enhanced accuracy in a visual reaction test requiring a decision and an additive effect was observed with respect to the fastest reaction times. However, in a test of executive function, where a distraction was included, caffeine exerted a negative effect on accuracy. Furthermore, the blue light only condition consistently outperformed caffeine when both congruent and incongruent distractions were presented. The visual reactions in the absence of a decision or distraction were also enhanced in the blue light only condition and this effect was most prominent in the blue-eyed participants. Overall, blue light and caffeine demonstrated distinct effects on aspects of psychomotor function and have the potential to positively influence a range of settings where cognitive function and alertness are important	Alertness encouraged by short wavelength "blue" light has been shown to enhance the performance of laboratory tasks requiring sustained attention.
1997	Begemann, S. H. A., G. J. van den Beld and A. D. Tenner. 1997. "Daylight, Artificial Light and People in an Office Environment, Overview of Visual and Biological Responses." *International Journal of Industrial Ergonomics* 20(3):231-239.	Long-term behavior /response of people has been studied in standard window zone offices during daytime working hours. Regular cell-offices were equipped with experimental lighting systems delivering lighting conditions that are known to influence human physiology. The results show that most people prefer to follow a daylight cycle instead of a constant level. Preferred lighting levels are significantly higher than today's indoor lighting standards and correspond to levels where biological stimulation can occur. The results strongly suggest that meeting biological lighting needs is very different from meeting visual needs. Results of two permanent occupants show striking differences in lighting settings, which correspond to individual circadian cycles and performance. This strengthens that present indoor lighting levels (and standards) are too low for biological stimulation. Medical research has shown that a prolonged lack of 'light vitamin' can cause health problems ranging from minor sleep and performance difficulties to major depressions. This inevitably suggests that 'poor' indoor lighting is the underlying cause of many of the health and performance problems. By naming this the 'ill-lighting syndrome' we may well have identified the fundamental mechanism that can result in many different negative health/performance effects. Creating healthy indoor lighting can be a simple form of preventive medicine and providing a new challenge for the lighting community.	This mechanism – reduction in melatonin and subsequent increase in alertness -- may be partly responsible for the observed improvements in worker performance demonstrated with full-spectrum office lighting systems
2000	Bell, J.L., Gardner, L.I., Landsittel, D.P. Slip and Fall-Related Injuries in Relation to Environmental Cold and Work Location in Above-Ground Coal Mining Operations. American Journal of Industrial Medicine 38:40-48 (2000)	Slip and fall-related injuries and environmental temperature was examined for mostly enclosed (inside vehicles, machinery, or buildings), outdoor (outside, not enclosed), and enclosed/outdoor jobs in the coal mining industry to see if differences existed among the three work locations that had varying exposure to cold temps.	Outside movement becomes a greater hazard at freezing temperatures for workers in all locations, not just outdoor workers. Intervention methods geared toward reducing injury incidents facilitated by cold weather must also be directed toward workers who spend time in enclosed locations.
2011	Bellia, L., F. Bisegna, and G. Spada. 2011. "Lighting in Indoor Environments: Visual and Non-Visual Effects of Light Sources with Different Spectral Power Distributions." *Building and Environment* 46(10):1984-1992.	This paper has the aim of introducing the recent discoveries in photobiology to those interested in lighting design, starting from a critical overview of traditional parameters since now used in lighting applications and then presenting a new theoretical approach to introduce non-visual parameters for lighting applications.	Lighting and illumination impacts on performance
1977	Bennett, C. A., A. Chitlangia and A. Pangrekar. 1977. "Illumination Levels and Performance of Practical Visual Tasks." *Proceedings of the Human Factors Society Annual Meeting* 21(4):322-325.	Two experiments studied the relation of illumination level and practical task performance, and the effects of age. Performance improved with illumination and declined with age. The North American illumination standards seem adequate but not excessive.	Participants engage in manual note taking, needle probing, and micrometer reading tasks (see Figure 6.6-7) typically had completion speeds asymptoting at between 50 and 200 lux (outcome very similar to earlier studies)

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1998	Bentley, T. A., and Haslam, R. A. 1998. Slip, Trip and Fall Accidents Occurring during the Delivery of Mail. Ergonomics 41(12):1859–1872.	This study sought to identify causal factors for slip, trip and fall accidents occurring during the delivery of mail. The most common initiating events in delivery falls were slips and trips. Slips most often occurred on snow, ice or grass, while trips tended to involve uneven pavements, obstacles and curbs. Half of all falls occurred during November-February and three-quarters of falls occurred between 7 and 9 a.m. Incidence rates for female employees were 50% higher than for their male colleagues.	Quantifies ice/snow slips falls
2000	Berkun, M.M. 2000. "Performance Decrement under Psychological Stress." *Journal of Human Performance in Extreme Environments* 5(1):	This paper evaluates performance under psychological stress.	Performance impact due to stressful environments
2015	Bernard, T.E., and I. Iheanacho. 2015. "Heat Index and Adjusted Temperature as Surrogates for Wet Bulb Globe Temperature to Screen for Occupational Heat Stress." *J Occup Environ Hyg* 12(5):323-333.	The purposes of this paper were: (1) to examine how well Heat Index and Adjusted Temperature estimated the wet bulb globe temperature (WBGT) index; and (2) to suggest how Heat Index and Adjusted Temperature can be used to screen for heat stress level.	Heat stress and potential methods for quantification
1976	Berson, B.L., and W.H. Crooks. 1976. *Guide for Obtaining and Analyzing Human Performance Data in a Materiel Development Project.* AD-A071 196, Perceptronics, Inc., Woodland Hills, California.	The report contains guidelines for conducting, analyzing, and reporting human factors engineering data	Guidance on reviewing human performance data
2003	Berson, D. M. 2003. "Strange Vision: Ganglion Cells as Circadian Photoreceptors." *Trends in Neurosciences* 26(6):314-320.	These intrinsically photosensitive retinal ganglion cells (ipRGCs) help to synchronize circadian rhythms with the solar day. They also contribute to the pupillary light reflex and other behavioral and physiological responses to environmental illumination.	Mechanism for blue/green light effects on performance
1980	Bertness, J. 1980. "Rain-Related Impacts on Selected Transportation Activities and Utility Services in the Chicago Area." *Journal of Applied Meteorology* 19(5):545-556.	Summarizes effects of rain on mass transportation	Summarizes effects of rain on mass transportation
1991	Bhattacharya, S.K. et al. 1991 Human Performance Capability in Psychomotor Tasks at Variable Difficulty Levels and Physiological Reactions under Noise and Heat Conditions	Performances of the psychomotor tasks were affected differently by noise and heat depending on the difficulty levels of the tasks.	Superior performance for tasks of memory and search, two hand coordination and reaction time, at moderate difficulty levels, but no distinct interaction effect was observed on the performance of tweezer dexterity.
2003	Biem, J., N. Koehncke, D. Classen and J. Dosman. 2003. "Out of the Cold: Management of Hypothermia and Frostbite." *Canadian Medical Association Journal* 168(3):305-311.	There are many types of cold-induced injury. In this article, we review the pathophysiology of the most common forms — hypothermia and frostbite — and provide strategies for the diagnosis and management of these conditions.	Cold stress injuries and performance collapses are more likely to occur as core temperatures fall below 35°C (95°F), with greater incidence rates at core temperatures below 28°C (85.4°F)
1972	Bittner, A. C. 1972. "The Effects of Temporal Sequencing on the Probability of Detecting an Audio-Visual Signal." In *Basic Capabilities Development Report (Tp-72-90).* Naval Missile Center, Point Mugu, CA.		Describes mechanism prospectively underling finding of suppression of a visual task by temporally and spatially congruent auditory noise (i.e., simultaneous auditory signals are processed ~30 milliseconds before simultaneously presented visual signals).
1985	Bittner, A.C. and J.C. Guignard. 1985. Human factors engineering principles for minimization of adverse ship motion effects: Theory and practice. Naval Engineers Journal 97(4):205-213.	Summarizes HF findings for two Navy workstations. Five potentially applicable human factors engineering (HFE) approaches to enhance seakeeping through prevention and mitigation of adverse ship motion effects, especially seasickness, were recognized and are discussed in this report in the light of observations made aboard the ship.	Effects of vibration on performance - especially "perceptual conflicts"
1985	Bittner, A.C., & Guignard, J.C. (1985b). Reply by the authors [to comments re: "Human factors engineering principles..."]. Naval Engineers Journal, 97(5), 109-111.	Discussion re: Bittner & Guignard, 1985.	Effects of vibration on performance - especially "perceptual conflicts"
1986	Bittner, A.C., Carter, R.C., Kennedy, R.S., Harbeson, M.M., & Krause, M. (1986). Performance Evaluation Tests for Environmental Research (PETER): Evaluation of 114 measures. *Perceptual and Motor Skills, 63,* 683-708.	This investigation was directed at evaluating nine cognitive ability tasks for repeated measures applications and inclusion in the Performance Evaluation Tests for Environmental Research (PETER) battery. In the first study, five tasks from the Moran Battery, which were adapted from the French kit of factor-referenced tests, were administered to 18 subjects daily for 13 workdays. In the second study, four tasks from the Carter and Sbisa Computer Generated Battery were administered daily to 17 subjects (12 in common with first study) for 15 workdays. Examination of the means, variances, and interday reliabilities, together with factor analysis of the cross-task correlations, led to the recommendation of four tasks. Tasks recommended for repeated measures applications were Vertical Addition, Perceptual Speed, Grammatical Reasoning, and Flexibility of Closure.	Demonstration of both the changes in task structure with practice and method to determine when, if ever, a task has become stable with practice.
1997	Bittner, A.C., Jr., and R.A. Kinghorn. 1997. Human Engineering Evaluation of CGC Ida Lewis (WLM 551). Battelle Seattle Research Centers, Seattle, WA.		Demonstration and discussion of adverse effects of augmented blue lighting on detection of distant targets at night (vs. classical redlighting).

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2010	Bjursten, H., P. Ederoth, E. Sigurdsson, M. Gottfredsson, I. Syk, O. Einarsson, et al. 2010. "S100B Profiles and Cognitive Function at High Altitude." *High Altitude Medical Biology* 11:31-38	Exposure to high altitude can lead to acute mountain sickness (AMS) and high altitude cerebral edema (HACE). In this study we investigated the effect of high altitude on neurocognitive function and S100B release. Increased S100B release has been hypothesized to signify a loss of integrity in the blood-brain barrier (BBB). Seven healthy volunteers trekked to Capanna Regina Margherita (4554 m above sea level) in the Monte Rosa massif. During ascent and descent, five test events were undertaken; participants underwent neurocognitive testing, Lake Louise scoring (LLS), and blood sampling to measure levels of S100B. The blood tests revealed that S100B levels increased 42% to 122% from baseline, and mean LLS increased from 0.57 to 2.57. A significant correlation was observed between both S100B levels and LLS and S100B and some neurocognitive scores. The study indicates that S100B can be released by a mild hypoxia during AMS. Moreover, an observed correlation between S100B and a lower score on neurocognitive tests suggests that the pathogenetic mechanisms may be linked. The study indicates that a decline in cognitive function is associated with symptoms of AMS.	Hypoxia results as a secondary effect of heat stress, and effects of acute hypoxia can range from fatigue to neural damage to the brain (as discussed herein vis-avis altitude).
2004	Blake, D.W., Hummel, J.R. Establishing Human Performance (Decision Making) and Natural Environment Consistency Across Integrated Naval Simulations.	Military performance is affected by both natural environmental conditions and human performance. As increased automation is occurring, it must incorporate the human decision making and environmental conditions.	Functional requirements must insure relevant interactions between human decision making and the environmental condition. Must incorporate all aspects in testing of systems.
2012	Blazejczyk, K., Y. Epstein, G. Jendritzky, H. Staiger and B. Tinz. 2012. "Comparison of Utci to Selected Thermal Indices." *International Journal of Biometeorology* 56(3):515-535.	Over the past century more than 100 indices have been developed and used to assess bioclimatic conditions for human beings. The majority of these indices are used sporadically or for specific purposes. Some are based on generalized results of measurements (wind chill, cooling power, wet bulb temperature) and some on the empirically observed reactions of the human body to thermal stress (physiological strain, effective temperature). Those indices that are based on human heat balance considerations are referred to as "rational indices". Several simple human heat balance models are known and are used in research and practice. This paper presents a comparative analysis of the newly developed Universal Thermal Climate Index (UTCI), and some of the more prevalent thermal indices. The analysis is based on three groups of data: global data-set, synoptic datasets from Europe, and local scale data from special measurement campaigns of COST Action 730. We found the present indices to express bioclimatic conditions reasonably only under specific meteorological situations, while the UTCI represents specific climates, weather, and locations much better. Furthermore, similar to the human body, the UTCI is very sensitive to changes in ambient stimuli: temperature, solar radiation, wind and humidity. UTCI depicts temporal variability of thermal conditions better than other indices. The UTCI scale is able to express even slight differences in the intensity of meteorological stimuli.	THE UTCI thermal index -- one of the engineering alternatives to WGBT -- is compared to other indices.
1998	Borg, G. 1998. *Borg's Perceived Exertion and Pain Scales,* Human Kinetics Publishers, Champaign, IL, US. ISBN 0-88011-623-4 (Paperback).	This book contains information about methods for measuring subjective somatic symptoms. The main focus is on the presentation of 2 scaling methods: the Borg RPE scale and the Borg CR10 scale. The Borg RPE scale is a scale for ratings of perceived exertion (RPE). It is a tool for estimating effort and exertion, breathlessness, and fatigue during physical work. The Borg CR10 scale is a category-ratio (CR) scale anchored at the number 10, which represents extreme intensities. It is a general intensity scale for most subjective magnitudes that with special anchors can be used to measure exertion and pain. A basic foundation for this book is the acceptance of a human as a psychosomatic whole. This means that psychological factors, such as personality, psychosocial factors, fear, and anxiety, affect somatic responses. It also means, however, that somatic functioning and signs of diseases can be studied psychologically, using human perception as a diagnostic instrument. This book deals primarily with the latter aspect. (PsycINFO Database Record (c) 2016 APA, all rights reserved)	Direct estimation scales -- pain and exertion -- with potential for identifying comparable levels of discomfort and/or POR across ECs
2015	Borisuit, A., F. Linhart, J. L. Scartezzini and M. Munch. 2015. "Effects of Realistic Office Daylighting and Electric Lighting Conditions on Visual Comfort, Alertness and Mood." *Lighting Research & Technology* 47(2):192-209.		Effects of lighting on performance requirements
2008	Botteldooren, D., B. De Coensel, B. Berglund, M. E. Nilsson and P. Lercher. 2008. "Modeling the Role of Attention in the Assessment of Environmental Noise Annoyance." In Proc. 9th Congress of the International Commission on the Biological Effects of Noise (ICBEN 2008), pp. 617-625. Foxwoods, CT. ed: A.-M. Fillet. ICBEN. https://biblio.ugent.be/publication/678988/file/679506.	Community noise effects in general and noise annoyance in particular are mostly studied by relating them to exposure through blind statistical analyses of large datasets. This paper reports on a specific part of a quite different approach. Using mathematical simulation of basic perception and psychophysical mechanisms for a large synthetic population, insight is sought into the mechanisms underlying the emergence of noise effects. This is achieved by comparing – in a phenomenological way – the statistics of the data gathered from the simulated synthetic population to that of the real population. This paper focuses on modeling the role of attention. Attention could play a role in two distinct aspects of the process: firstly, attention can be drawn away from other tasks by the environmental sound or tasks requiring sustained attention can suppress the noticing of the environmental sound; secondly, attention can jump between sounds in multisource sonic environments. In modeling this dual role of attention, care must be taken to simplify existing knowledge on these aspects of perception in such a way that the model can be used to study long exposure times and large populations. Such modeling may support the assessment of real life situations where multiple environmental sounds interfere and cause noise annoyance. Example simulations involving exposure to railway noise, road traffic noise, natural sound and sound produced by the individual's own activity show the influence of attention on the model outcome.	Many of noise's effects on performance -- as arguably for several other ECs --may be tied to its observed tendency to produce arousal, stress, and annoyance that affects an individual's ability to focus attention on the task at hand.
2003	Bourne, L. E. and R.A. Yaroush. 2003. Stress and cognition: A cognitive psychological perspective. National Aeronautics and Space Administration Grant Number NAG2-1561. Available at https://ntrs.nasa.gov/search.jsp?R=20040034070.	Lit review with largely inconclusive/confounding data.	Covers many topics
1939	Bowden, F. P., and Hughes, T. P. 1939. The Mechanism of Sliding on Ice and Snow. Proceedings of the Royal Society of London. Series A, Mathematical and Physical Sciences 172:280-298.	Describes the physics behind slipping on ice/snow	Ice/snow mechanism of action for slipping

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2014	Bradshaw, V. 2014. *The Building Environment; Active and Passive Control Systems, 3d Edition.* Wiley: Hoboken, New Jersey	To capitalize on today's rapidly evolving, specialized technologies, architects, designers, builders, and contractors work together to plan the mechanical and electrical equipment that controls the indoor environment of a building. The Building Environment: Active and Passive Control Systems, Third Edition helps you take advantage of design innovations and construction strategies that maximize the comfort, safety, and energy efficiency of buildings.	Thermal comfort definition as "[t]he state in which homeostatic mechanisms easily maintain the balance between heat loss and heat retention…" related to concept of thermal balance equation.
2001	Brainard, G. C., J. P. Hanifin, J. M. Greeson, B. Byrne, G. Glickman, E. Gerner and M. D. Rollag. 2001. "Action Spectrum for Melatonin Regulation in Humans: Evidence for a Novel Circadian Photoreceptor." *The Journal of Neuroscience* 21(16):6405-6412.	Light is a potent regulator of systemic physiology. Specifically, environmental light is the primary stimulus for regulating circadian rhythms, seasonal cycles, and neuroendocrine responses in many mammalian species including humans (1, 2, 3, 4). Shortly after the regulatory capacity of light was demonstrated in humans, light was tested as a therapeutic intervention for treating winter depression or Seasonal Affective Disorder (5, 6, and 7). Since then, twenty years of clinical studies have confirmed that light therapy is effective for treating winter depression (8, 9, and 10). In addition, light therapy has been studied as a treatment for selected circadian sleep disorders, nonseasonal depression, menstrual disturbances, eating disorders as well as re-entraining circadian physiology relative to the challenges of shift work or intercontinental air travel	Report regarding the novel retinal receptors, sensitive to blue/green light – this subclass of retinal-ganglion cells was recently found to provide input affecting both visual sensitivity and the human sleep-arousal cycle
2007	Branscome, T.A., and J.O. Grynovicki. 2007. *An Investigation of Factors Affecting Multi-Task Performance in an Immersive Environment.* ARL-TR-4325, Army Research Laboratory, Aberdeen Proving Ground, Maryland.	This report presents the results of a study included in a series of investigations designed to increase fundamental knowledge and understanding of the factors affecting multi-task performance in a military environment.	Multi-tasking in harsh environment and associated performance impact
2014	Brearley, M., P. Harrington, D. Lee, and R. Taylor. 2014. "Working in Hot Conditions—a Study of Electrical Utility Workers in the Northern Territory of Australia." *J Occup Environ Hyg* 12(3):156-162. http://dx.doi.org/10.1080/15459624.2014.957831.	For electrical utility workers who periodically work at height, in confined space, and in proximity to live power sources, the impact of the climate may be considered a hazardous condition. Therefore, this study examined the physiological and fluid balance responses of 20 power network workers	Heat stress and human performance impact
1970	Broadbent, D. E. 1970. Human performance in noise. In C. M. Harris (Ed.), Handbook of Noise Control (2nd ed. Pp. 1-19). McGraw-Hill. New York, NY.	A revision and expansion of an established reference covering the solution of noise problems in industrial, business, residential and community environments. The Handbook's scope has been significantly increased to include acoustical measurements. It covers practical information on how noise is produced, how it is measured, how it affects people and how it can be controlled. Formerly entitled "Handbook of noise control", this third edition now includes important material on acoustical measurement, offers practical solutions to more troublesome environmental problems in daily noise, and incorporates both SI units and US customary units.	Developer of noise-arousal theory where Job related stress effects are more pronounced when noise is louder and/or start and stop out of the worker's control (vs when workers have some control over the noise).
1960	Broadbent, D. E., and F.A.J. Little. 1960. Effects of noise reduction in a work situation. Occupational Psychology 34, 133-140.		Mitigation of noise in occupational setting; paper cited in Echeverria et al. 1994 has relevance to current review
1988	Brodsky, H., and Hakkert, A. S. 1988. Risk of a Road Accident in Rainy Weather. Crash Analysis and Prevention 20:161-176.	Quantifies accident likelihood during rainy weather. Results indicate that the added risk of an injury accident in rainy conditions can be substantial: two to three times greater than in dry weather. And when a rain follows a dry spell the hazard could be even greater.	Expectations based on recent experience can effect behavior and accident rate during rain
1997	Brown, B. and K. Baass. 1997. "Seasonal Variation in Frequencies and Rates of Highway Accidents as Function of Severity." *Transportation Research Record: Journal of the Transportation Research Board* 1581:59-65.	The lowest numbers and rates of death and serious injury occur in winter months. However, accidents with material damage only are most frequent, and have their highest rates, in winter months. Winter is associated with low mortality and serious injury and high numbers and rates of minor accidents. There is a negative correlation between the monthly rankings of injury rates when severe injuries and deaths are compared with material-damage-only accidents. These results underline a point that deserves more attention: conditions associated with mortality and serious injury are in many ways distinct and different from conditions associated with minor injuries and material damage-only accidents and are poorly, and even negatively in the present example, correlated with these conditions.	Clearly drivers are being more careful during ice/snow presence - change of behavior reduces accidents paradoxically
2008	Budd, G. M. 2008. Wet-bulb Globe Temperature (WBGT) – Its History and Its Limitations. Journal of Science and Medicine in Sport 11 (1), 20-32.	Describes the history of the WBGT measure and its limitations	Heat, Cold, Humidity attributes/units
2001	Bullough, J. D. and M. S. Rea. 2001. "Driving in Snow: Effect of Headlamp Color at Mesopic and Photopic Light Levels." Presented at SAE 2001 World Congress, p. 11. 5 March 2001, Detroit, MI.	Many individuals believe that yellow headlights are preferable to white headlights when driving at night during a snowfall. Although evidence exists to support the claim that yellow light can be perceived as less "glaring" or "distracting" than white light of equal luminance, it is not clear whether backscattered light of different colors are differentially effective for driver comfort or for driver performance. This study investigates a potential mechanism that could support the supposed benefit of yellow headlamps for reducing the detrimental effects of backscattered light to drivers at night. The results suggest that under low light levels when the visual field is dominated by a dynamic field of visual "noise" (like that caused by backscattered light from falling snow), performance of a tracking task similar to driving is reduced in accordance with the scotopic (rod-stimulating) content of the visual noise. Contrary to conventional understanding, rods might affect performance up to luminances of 65 cd/m2.	Demonstration that yellow headlamps tend to be subjectively less glare-inducing in precipitation than conventional

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2011	Bye, L., et al. 2011. *International HRA Empirical Study – Phase 2 Report, Results from Comparing HRA Method Predictions to Simulator Data from Sgtr Scenarios.* NUREG/IA-0216, Volume 2, Office of Nuclear Regulatory Research, Washington, D.C. ML11250A010.	International HRA empirical study. USNRC; Paul Scherrer Institute, Switzerland; Sandia National Lab; Scientech; OECD Halden Reactor Project, Norway. Vol 1 - overall approach and pilot results from comparing HRA methods to simulator performance data. Vol 2 - comparing HRC predictions to simulator data from SGTR scenarios. Vol 3 - comparing HRC predictions to HAMMLAB simulator data on LOFW scenarios.	Background on HRA
1969	Cabanac, M. (Cabanac, M. 1969. "Pleasantness or Unpleasantness of a Thermal Sensation and Homeothermia." Physiology & Behavior 4(3):359-364.	A thermal sensation is composed by two elements, the first discriminative is the description of the physical characteristics of the stimulus, the second is affective (pleasant-unpleasant). A quantitative measurement of the second has been made on human subjects using an arbitrary scale. The thermal stimulus was limited in time, and in space to the left hand. Two internal temperatures were recorded and the skin temperature controlled by water bath immersion to the chin. The preference or aversion for the stimulus was independant of the mean skin temperature but depended directly on the internal temperature of the subjects. The same stimulus could give the opposite affective sensation according to the internal state. Within the limits of pain (15°C and 45°C for 30 s) cold was preferred during hyperthermia and warm during hypothermia. Since the same phenomenon existed during fever but was adapted to a higher level of internal temperature, it can be concluded that the affective part of the sensation is tied down to the defense of the thermoregulatory set point.	Supporting psychological explanations for cold's effects on performance (discomfort affects performance, before core temp. begins to drop), this is one of several studies suggest that the temperature of extremities (hands and feet) is particularly important to the experience of discomfort. As temperature declines, workers tend to experience the least discomfort just after the point when cold extremities have signaled the brain to engage adaptive heat production and/or conservation.
1972	Cabanac, M., B. Massonnet and R. Belaiche. 1972. "Preferred Skin Temperature as a Function of Internal and Mean Skin Temperature." *Journal of Applied Physiology* 33(6):699-703.	Healthy men were immersed in a stirred bath maintained at five constant temperatures, 23, 28, 33, 38, and 40 degrees C. The bath temperature was chosen by the experimenter. Esophageal temperature was recorded. The subject's left hand was placed outside the bath in a gove perfused by a continuous water flow. The glove temperature was adjusted from inside the bath by the subject himself with his right hand. The subject could thus obtain any glove temperature between 15 and 45 degrees C. The subjects were instructed to choose the most pleasurable glove temperature. The results confirmed previous results showing that thermal pleasure depended mostly upon internal temperature. At a constant bath temperature, hyperthermic subjects selected cool glove temperatures and hypothermic subjects selected warm glove temperatures. There was an inverse relationship between internal temperature and glove temperature. Mean skin temperature, estimated from bath temperature, also had an influence. Results can be summarized by the equation Tg pref=-0.3+Tb (Tex - 36.3) + 44.	Supporting psychological explanations for cold's effects on performance (discomfort affects performance, before core temp. begins to drop), this is one of several studies suggest that the temperature of extremities (hands and feet) is particularly important to the experience of discomfort. As temperature declines, workers tend to experience the least discomfort just after the point when cold extremities have signaled the brain to engage adaptive heat production and/or conservation.
1971	Cabanac, M., D. J. Cunningham and J. A. Stolwijk. 1971. "Thermoregulatory Set Point During Exercise: A Behavioral Approach." *Journal of Comparative and Physiological Psychology* 76(1):94-102.	Examined the finding that response to a peripheral thermal stimulus is an indicator of thermal status with respect to the thermoregulatory set point. 6 men and 3 women were provided with a glove perfused with water, adjustable in temperature from 15-45–C. Ss were asked to maintain the glove temperature at the level they considered most pleasant. In response to environmental temperatures ranging 15-45–C and to exercise at levels of 500 and 1,000 kgm/min, the selected glove temperature ranged 20-40–C. The preferred glove temperature (a) depended strongly on internal body temperature, (b) was affected to a lesser extent by mean skin temperature, and (c) was not affected by exercise alone. Results suggest there is no change in thermoregulatory set point during exercise. (27 ref.) (PsycINFO Database Record (c) 2016 APA, all rights reserved).	Supporting psychological explanations for cold's effects on performance (discomfort affects performance, before core temp. begins to drop), this is one of several studies suggest that the temperature of extremities (hands and feet) is particularly important to the experience of discomfort. As temperature declines, workers tend to experience the least discomfort just after the point when cold extremities have signaled the brain to engage adaptive heat production and/or conservation.
2007	Cajochen, C. 2007. Alerting effects of light. Sleep Medicine Reviews 11:453-464.	Review article on the effects light exposure has on alertness and behavior associated with alertness	Lighting effects on alertness and behavior/cognition
2014	Cajochen, C., S. L. Chellappa and C. Schmidt. 2014. "Circadian and Light Effects on Human Sleepiness–Alertness." In *Sleepiness and Human Impact Assessment,* pp. 9-22 eds: S. Garbarino, L. Nobili and G. Costa. Ch. 2. Springer, Milano, Italia.	Most of our behavioral and physiological activities are modulated or regulated by endogenous clocks, chief among them the circadian (i.e., about a day) clock. Optimally located in the suprachiasmatic nuclei (SCN) of the anterior hypothalamus [1, 2], the circadian pacemaker in the SCN receives light information via the retinohypothalamic tract [3] directly from the retina's classical and nonclassical photoreceptors.	Alertness encouraged by higher intensity and short wavelength light has been shown to enhance the performance of laboratory tasks requiring sustained attention.
2013	Caldwell, B.S. 2013. "Robust Resilience: Metaphor and Meaning in Assessing System Performance Ranges." *Journal of Human Performance in Extreme Environments* 11(1):	This paper discusses important elements in the consideration of resilience as a quantitative metric to improve consistency and clarity of evaluation in engineering systems. Rather than simply a binary attribute of systems, resilience should be considered in terms of system performance measures as affected by environmental conditions	Potential framework for quantifying human performance impacts from environmental stressors

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2011	Callejon-Ferre, A.J., F. Manzano-Agugliaro, M. Diaz-Perez, and J. Carreno-Sanchez. 2011. "Improving the Climate Safety of Workers in Almería-Type Greenhouses in Spain By predicting the Periods When They Are Most Likely to Suffer Thermal Stress." Applied Ergonomics 42(2):391-396.	The humidex and wind-chill indices were used to determine the periods in which laborers working in Almería-type greenhouses in southeastern Spain are most likely to suffer conditions able to induce heat and cold stress. Over 500,000 pieces of data for wet and dry bulb temperatures and relative humidity, recorded over a period in excess of five years by a weather station located in an Almería-type greenhouse containing a grass crop, were used in the calculation of these indices. The wind-chill index results showed cold stress never to be a problem, but the humidex index results showed that conditions under which heat stress could develop were common in the warmer months. A clock diagram was produced showing the hours when heat stress is likely to occur in each month of the year. This information could be used to improve the conditions of laborers working in this type of greenhouse; some ways of reducing their exposure to heat stress-inducing conditions are discussed.	The researchers devised a clock diagram showing the hours when heat stress is likely to occur at a particular location in each month of the year.
2003	CaÑas, J., J. Quesada, A. AntolÍ, and I. Fajardo. 2003. "Cognitive Flexibility and Adaptability to Environmental Changes in Dynamic Complex Problem-Solving Tasks." *Ergonomics* 46(5):482-482.	This paper describes theories that explain human performance based on the interaction between cognitive mechanisms and environment.	Performance impacts related to cognition
1999	Casali, J. G. and G. S. Robinson. 1999. "Noise in Industry: Auditory Effects, Measurement, Regulations, and Management." In *The Occupational Ergonomics Handbook,* pp. 1661-1692, 2nd ed. Ed: W. K. W. Marras.		Handbook summary of industrial noise -- measurement, effects, regulations and management
2010	Cassenti, Daniel N., Troy D. Kelley, and Richard A. Carlson. 2010. "Modeling the workload-performance relationship." In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting,* vol. 54, no. 19, pp. 1684-1688. SAGE Publications, 2010.	(IMPRINT) includes an algorithm to predict mental workload. The algorithm was developed using subject matter expert ratings of workload tasks. We aimed to enhance this capability by developing algorithms using data from four new studies investigating change in performance as demands on mental resources increase. The results indicate three task types of similar difficulty and one task type of much greater difficulty. We then map these to our hypothesized workload function. Finally, we propose a way forward in modeling performance as a function of workload in IMPRINT.	Background for IMPRINT
2001	Castellani J.W., Young, A.J., O'Brien, C, Stulz, D.A., Sawka, M.N., Pandolf, K.B. 2001. Cold Strain Index Applied to Exercising Men in Cold-Wet Conditions. *American Journal of Physiology Regulatory Integrative Comparative Physiology* 281(6):R1764-1768.	Men were tested using a cold stress strain index to determine physiological cold strain in real time.	Cold stress impact on performance
2007	Castellani, J.W., O'Brien, C., Tikuisis, P, Sils, I.V., and Xu, X. 2007. Evaluation of two cold thermoregulatory models for prediction of core temperature during exercise in cold water. J Appl Physiol 103: 2034-2041, 2007.	Studied cold thermoregulatory model responses during exercise and immersion in cold water.	Thermoregulatory models cannot be used for exercise study. Only good for sedentary cold exposure.
2002	Cham, R. and M. S. Redfern. 2002. "Changes in Gait When Anticipating Slippery Floors." *Gait & Posture* 15(2):159-171.	Falls precipitated by slipping are listed among the leading causes of injuries. The biomechanical analysis of such events is a necessary component of the slips/falls prevention research. One of the challenges of biomechanical studies is reproducing the unexpected nature of real-life slipping accidents. Thus, the goal of this study was to quantify changes in gait biomechanics when subjects anticipate slippery environments. Foot ground reaction forces and body dynamics of 16 subjects were recorded during level walking and descending ramps of varying frictional properties and inclination. Gait biomechanics were compared among three types of dry trials: (1) baseline (subjects knew the floor was dry); (2) anticipation (subjects were uncertain of the contaminant condition, dry, water, soap or oil); and (3) recovery trials recorded after a contaminated trial (subjects again knew the floor was dry). Subjects were asked to walk as naturally as possible throughout testing. Anticipation trials produced peak required coefficient of friction (RCOFpeak) values that were on average 16–33% significantly lower than those collected during baseline trials, thus reducing slip potential. During recovery trials, RCOFpeak values did not return to baseline characteristics (5–12%lower). Postural and temporal gait adaptations, which affected ground reaction forces, were used to achieve RCOFpeak reductions. Statistically significant gait adaptations included reductions in stance duration (SD) and loading speed on the supporting foot, shorter normalized stride length (NSL), reduced foot-ramp angle and slower angular foot velocity at heel contact. As a result of these adaptations, anticipation of slippery surfaces led to significant changes in lower extremity joint moments, a reflection of overall muscle reactions. Thus, this study suggests that significant gait changes are made when there is a potential risk of slipping even though subjects were asked to walk as naturally as possible. Insights are also gained into the adaptations that are used to reduce the potential of slips/falls.	Demonstrated gait and marked walking speed changes in anticipation of slippery surface.
2007	Chang, F.L., Sun, YM, Chuang, K.H., Hsu, D.J. 2007. Work fatigue and physiological symptoms in different occupations of high-elevation construction workers. Applied Ergonomics 40 (2009) 591-596.	Workers in high elevations were studied to determine how fatigue and physiological symptoms affected their ability to perform work. It was determined that it did play a role, but that role varied amongst the studied group. They must chose a healthy life style and behavior in job training to be more protective.	Fatigue and physiological conditions can lead to degradation of work

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2007	Chang, S.-K., and C.G. Drury. 2007. "Task Demands and Human Capabilities in Door Use." Applied Ergonomics 38(3):325-335.	This paper provides a classification scheme for doors based on human/door interaction and a prototypical task analysis of door use. Two observational studies were performed on a particular type of door. The first observed 1600 human/door interactions and found that people's use of force-enhancing strategies increased for larger doors, particularly for people of smaller stature. The second observed 800 interactions with push doors and found that the point where force is exerted is higher for taller individuals and closer to the center of the door than is typically assumed for placing handles. The second study was partly corroborated by measuring the position of wear patterns on doors. As is expected in human factors, the way people used doors was a function of both task demands and human capabilities.	Door interactions background
2016	Chang, W.-R., S. Leclercq, T. E. Lockhart and R. Haslam. 2016. "State of Science: Occupational Slips, Trips and Falls on the Same Level." *Ergonomics* 59(7):861-883.	Occupational slips, trips and falls on the same level (STFL) result in substantial injuries worldwide. This paper summarizes the state of science regarding STFL, outlining relevant aspects of epidemiology, biomechanics, psychophysics, tribology, organizational influences and injury prevention. This review reaffirms that STFL remain a major cause of workplace injury and STFL prevention is a complex problem, requiring multi-disciplinary, multi-faceted approaches. Despite progress in recent decades in understanding the mechanisms involved in STFL, especially slipping, research leading to evidence-based prevention practices remains insufficient, given the problem scale. It is concluded that there is a pressing need to develop better fall prevention strategies using systems approaches conceptualizing and addressing the factors involved in STFL, with considerations of the full range of factors and their interactions. There is also an urgent need for field trials of various fall prevention strategies to assess the effectiveness of different intervention components and their interactions.	Reflecting the rule that nighttime supplementary lighting should only be as intense as is absolutely required for the task, because anything above this level extends the time necessary for a worker's eyes to adapt when leaving the lighted work area and increases their susceptibility to trip-and-fall accidents.
2005	Chase, B., W. Karwowski, M.E. Benedict, and P.M. Queseda. 2005. "Effects of Thermal Stress on Dual Task Performance and Attention Allocation." *Journal of Human Performance in Extreme Environments* 8(1-2):27-39.	The results of this study showed an inability to allocate attention, while maintaining accurate performance, under thermal stress.	Thermal stress impacts on performance
1965	Chatonnet, J. and M. Cabanac. 1965. "The Perception of Thermal Comfort." *International Journal of Biometeorology* 9(2):183-193.	26 subjects were exposed either to constant temperature in a water bath or to different air temperatures. A differentiation was made between the comfort temperature and the conscious cutaneous thermal sensation. When thermal sensation of the hand was tested for different internal temperatures it was found that the same superficial (skin) temperature could be agreeable or disagreeable depending on the existing internal temperature. Those skin temperatures which lead to normalization of the internal temperature were agreeable; conversely those skin temperatures which increased deviation of the internal temperature from normal were disagreeable. In man there are two sensory components in thermal perception, one superficial discriminative, and one deep which permits appreciation of agreeable and disagreeable.	Temperature of extremities (hands and feet) is particularly important to the experience of discomfort. As temperature declines, workers tend to experience the least discomfort just after the point when cold extremities have signaled the brain to engage adaptive heat production and/or conservation but then workers experience increasing discomfort as extremities remain cold over time. Deep-body (core) temperature plays a secondary role to that of extremity temperature in discomfort and tends to correspond more closely with physiological effects
2011	Chellappa, S. L., R. Steiner, P. Blattner, P. Oelhafen, T. Götz and C. Cajochen. 2011. "Non-Visual Effects of Light on Melatonin, Alertness and Cognitive Performance: Can Blue-Enriched Light Keep Us Alert?" *PloS one* 6(1):e16429.	Findings suggest that the sensitivity of the human alerting and cognitive response to polychromatic light at levels as low as 40 lux, is blue-shifted relative to the three-cone visual photopic system. Thus, the selection of commercially available compact fluorescent lights with different color temperatures significantly impacts on circadian physiology and cognitive performance at home and in the workplace.	Lighting effects on alertness and behavior/cognition
2010	Chen, W.-L., Y.-C. Shih and C.-F. Chi. 2010. "Hand and Finger Dexterity as a Function of Skin Temperature, EMG, and Ambient Condition." *Human Factors* 52(3):426-440.	Studied relationship between finger, arm, forearm dexterity and the factors of skin temperature, electromyograph (EMG), and ambient condition during a manual activity.	Dexterity, EMG, and skin temperature fell with prolonged cooling, but the EMG of the flexor digitorum superficialis remained almost unchanged
1953	Cherry, E. C. 1953. "Some Experiments on the Recognition of Speech, with One and with Two Ears." *The Journal of the Acoustical Society of America* 25(5):975-979.	This paper describes a number of objective experiments on recognition, concerning particularly the relation between the message received by the two ears. Continuous speech is used. Two types of test are reported :(a) the behavior of a listener when presented with two speech signals simultaneously and (b) behavior when different speech signals are presented to his two ears.	Speech processing background
2008	Cheung, S.S., Reynolds, L.F., Macdonald, M.A.B, Tweedie, C.L., Urquhart, R.L., Westwood, D.A. 2008. Effects of local and core body temperature on grip force modulation during movement-induced load force fluctuations. Eur J Appl Physiol (2008) 103:59-69.	Studied impact of impaired manual hand functioning due to exposure to cold temperatures.	Cold stress on manual hand functioning

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2000	Cheung, S.S., T.M. McLellan, and S. Tenaglia. 2000. "The Thermophysiology of Uncompensable Heat Stress. Physiological Manipulations and Individual Characteristics." *Sports Medicine* 29:329–359	In many athletic and occupational settings, the wearing of protective clothing in warm or hot environments creates conditions of uncompensable heat stress where the body is unable to maintain a thermal steady state. Therefore, special precautions must be taken to minimize the threat of thermal injury. Assuming that manipulations known to reduce thermoregulatory strain during compensable heat stress would be equally effective in an uncompensable heat stress environment is not valid. In this review, we discuss the impact of hydration status, aerobic fitness, endurance training, heat acclimation, gender, menstrual cycle, oral contraceptive use, body composition and circadian rhythm on heat tolerance while wearing protective clothing in hot environments. The most effective countermeasure is ensuring that the individual is adequately hydrated both before and throughout the exercise or work session. In contrast, neither short term aerobic training or heat acclimation significantly improve exercise-heat tolerance during uncompensable heat stress. While short term aerobic training is relatively ineffective, long term improvements in physical fitness appear to provide some degree of protection. Individuals with higher proportions of body fat have a lower heat tolerance because of a reduced capacity to store heat. Women not using oral contraceptives are at a thermoregulatory disadvantage during the luteal phase of the menstrual cycle. The use of oral contraceptives eliminates any differences in heat tolerance throughout the menstrual cycle but tolerance is reduced during the quasi-follicular phase compared with non-users. Diurnal variations in resting core temperature do not appear to influence tolerance to uncompensable heat stress.	Discusses misassumption that methods for amelioration of heat stress effects are operable when heat stress is uncompensable
2005	Chi, C.-F., T.-C. Chang, and H.-I. Ting. 2005. "Accident Patterns and Prevention Measures for Fatal Occupational Falls in the Construction Industry." Applied Ergonomics 36(4):391-400.	Summary of findings of a naturalistic study on construction accidents.	Relevant to ice/snow slipping.
2005	Choy, E., and J. Ruwanpura. 2005. "Situation Based Modeling for Construction Productivity." Construction Research Congress 2005, pp. 1-10. American Society of Civil Engineers, http://dx.doi.org/10.1061/40754(183)131.	Situation-based simulation modeling tool to model triggering to predict productivity at construction sites.	Interactions among tasks, triggering
2012	Clark, C., and P. Sorqvist. 2012. "A 3 Year Update on the Influence of Noise on Performance and Behavior." *Noise & Health* 14(61):292-296.	This paper reviews developments in the field over the past 3 years, highlighting current areas of research, recent findings, and ongoing research in two main research areas: Field studies of noise effects on children's cognition and experimental studies of auditory distraction.	Noise impacts on cognition and communication
1962	Clark, R.E. and C.E. Jones. 1962. "Manual Performance during Cold Exposure as a Function of Practice Level and the Thermal Conditions of Training." *Journal of Applied Psychology* 46:276–80.	Effects of varied thermal experience (warm or cold hands) during 3 weeks of training on a standard manual task. The results were as follows: (a) 1 day of cold-hand training significantly reduces the size of a manual decrement usually associated with cold exposure, but continued cold experience did not; (b) skill level on the task per se did not interact with the cold induced performance decrements; and (c) the thermal conditions associated with performance on the task appeared to become part of the stimulus complex eliciting correct manual responses when these thermal conditions were maintained for a large number of trails, i.e., the Ss learned, not merely to perform on the task, but to perform with warm, or cold hands specifically.	Relevant to cold exposure effects on fine motor performance
1958	Clarke R.S.J., R.F. Hellon, and A.R. Lind. 1958. "The Duration of Sustained Muscle Contractions of the Human Forearm at Different Muscle Temperatures." *Journal of Physiology (Lond)* 143:454-473.	Summarizes an experiment to determine effects on muscle contraction when the forearm is heated or cooled by water	Effects of Heat/Cold in the context of Standing Water on fine motor behavior.
1976	Cohen, A. 1974. *Industrial Noise and Medical Absence, and Accident Record Data on Exposed Workers.* EPA 550/9-73-0008, US Environmental Protection Agency, Washington DC.		Classical relationships between increased noise exposures and associated medical absence and accidents.
2015	Cohen, I., W.-P. Brinkman, and M.A. Neerincx. 2015. "Modelling Environmental and Cognitive Factors to Predict Performance in a Stressful Training Scenario on a Naval Ship Simulator." Cognition, Technology & Work 1-17.	This paper presents and assesses a refined version of the cognitive performance and error (COPE) model that describes the effects of stressful events on decisions as a foundation for such a support tool. Within a high-fidelity simulator of a ship's bridge at the Royal Netherlands Naval College, students of the naval college ($n = 10$) were observed while completing a 2-h-long shadowing and boarding operation combined with a search-and-rescue operation. For every action, variables were measured: objective and subjective task demand, challenge and threat appraisal, and arousal based on heart rate and heart rate variability. The data supported the COPE model and were used to create predictive models. The variables could provide minute-by-minute predictions of performance that can be divided into performance rated by experts and errors. The predictions for performance rated by experts correlated with the observed data ($r = 0.77$), and 68.3 % of the predicted errors were correct. The error predictions concern the chances of making specific errors of communication, planning, speed, and task allocation. These models will be implemented into a real-time feedback system for trainees performing in stressful simulated training tasks.	Predictive model for cognitive performance impacts. COPE model variables provide minute-by minute predictions of performance that can be divided into performance rated by experts and errors.
1983	Coleshaw, S.R.K., R.N.M. Van Someren, A.H Wolff, H.M. Davis, and W.R. Keatinge. 1983. "Impaired Memory Registration and Speed of Reasoning Caused by Low Body Temperature." *Applied Physiology* 55:27-31.	Volunteers' body core temperatures were lowered by immersion in water at 15°C. Aspects of cognitive function were subsequently tested after rewarming had been started in water at 41°C when their skin was warm and they felt comfortable but their body core temperature remained low. Memory registration was found to be impaired progressively when core temperature fell from about 36.7"C; at core temperatures of 34- 35°C the impairment caused loss of approximately 70% of data that could normally be retained. However, recall of previously learned data was not impaired at these core temperatures. On a two-digit calculation test, speed of performance was impaired by about 50% at a core temperature of 34-35"C, but provided enough time was available, accuracy of performance was not reduced.	Effects of cold water exposure on memory and reasoning.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2013	Colman, J.M., H.K. Kahle, and E. Henriqson. 2013. "Is Performance Variability Necessary? A Qualitative Study on Cognitive Resilience in Forestry Work." *Journal of Human Performance in Extreme Environments* 11(1):	Forestry workers deal with complex, dynamic, high-hazard environmental conditions as a regular part of their work. Exposure to adverse environments and high risk is considered normal in the forestry industry.	Potential translatability of high-hazard environmental stressors to flood mitigation
1971	Colquhoun, W. P. (Ed.) 1971. *Biological rhythms and human performance.* New York: Academic Press.		This mechanism – light enhanced reduction in melatonin and subsequent increase in alertness -- may responsible for the observed improvements in worker performance demonstrated with full-spectrum lighting systems
2015	Comperatore, C. A., P. K. Ng and A. B. Carvalhais. 2015. "Design Standards Considerations and the Effective Prevention of Operator Fatigue." *Reviews of Human Factors and Ergonomics* 10(1):174-193.	In this chapter, we explore the need to develop specific guidance, tailored to consumers of fatigue risk management systems, outlining how to verify that program elements effectively control the incidence of operator fatigue. We advance the notion that without independent proof of efficacy, consumers are left to assume that program implementation and sustainment costs actually yield the desired results. Lacking this information perpetuates losses associated with fatigue-related performance degradation, health issues, and mishaps. Inspection and verification protocols require objective evidence, beyond surveys, to demonstrate that fatigue management program elements control the incidence of operator fatigue in the workplace. Scientific and technological advances facilitate the evaluation of fatigue management programs and the use of objective techniques to test circadian rhythm stability and alertness. However, consumers are yet to incorporate these test protocols and technological advances in their safety management system assurance infrastructure. The prevailing assumption has been that scientific tests and methodologies are beyond the reach of the consumer and fall in the purview of scientists and fatigue management professionals. In this chapter, we propose the use of the design basis plan in safety management systems as the assurance infrastructure to associate program inspection elements, fatigue leading indicators, and specific standards with compulsory review and approval activities. These assurance activities not only provide objective means to identify fatigue management program elements that fail to control the incidence of operator fatigue but also enable consumers to proactively implement necessary modifications.	Light enhanced reduction in melatonin and subsequent increase in alertness -- may be partly responsible for the observed improvements in worker performance demonstrated with green- and blue-augmented lighting systems
2007	Conway, G.E., J.L. Szalma, and P.A. Hancock. 2007. "A Quantitative Meta-Analytic Examination of Whole-Body Vibration Effects on Human Performance." *Ergonomics* 50(2):228-245.	Whole-body vibration exerts a substantive influence in many work environments. The primary objective for this work was to quantify such effects by identifying those moderating variables that influence the degree to which performance is affected.	Performance impacts due to vibration
2012	Cooper, M. A. and R. L. Holle. 2012. "Lightning Safety Campaigns - USA Experience." In Proc. *2012 International Conference on Lightning Protection (ICLP),* pp. 1-7. 2-7 Sept. 2012, Vienna, Austria. IEEE.	Although several individuals in the United States (US) were working on lightning safety efforts, it was not until the early 1990's that researchers from many fields of study began to work together as they became aware of others with similar interests. The first organized effort on a national scale was in 1998 when a multidisciplinary group of recognized lightning researchers and experts met at an American Meteorological Society meeting and agreed on the Lightning Safety Guidelines (LSG) which were published in a number of venues. Beginning in 2001, a Lightning Safety Awareness (LSA) campaign was initiated by the US National Oceanic and Atmospheric Administration (NOAA) with many of the LSG individuals as well as others [1.2]. This campaign, now called Lightning Safety Week (LSW), occurs the last full week of June annually. The LSW website (www.lightningsafety.noaa.gov) has become the premier lightning safety site with general information, games, puzzles, public service announcements as well as special sections for the media, teachers, boaters, and many other interests and concerns. LSW members and others have continued to be active in promoting lightning injury prevention, train others, and develop lightning safety themes such as 'When Thunder Roars, Go Indoors!' that can be learned by any age. An interactive game using a cartoon character 'Leon, the Lightning Safety Lion' was developed to help teach lightning safety to children but is well liked by adults as well. The materials from this website are all free for download, use and modification by anyone who is interested in injury prevention and lightning safety. Collectively, the LSW team and others have made themselves available for thousands of interviews with newspapers, radio and television, worked on dozens of documentaries, as well as continuing their own research and publication. There has been a steady decrease in the lightning fatality rate over the past twenty years of work with a rate of less than 0.1 million US population in each of the last three years, in part due to the educational efforts of this group and the media's support in disseminating lightning safety information.	Discusses the framework for a successful lightning safety program
2016	Cooper, M.A. and R.F. Edlich. 2016. Lightning Injuries. Accessed November 4, 2016 from Medscape.com, Drugs & Diseases. http://emedicine.medscape.com/article/770642-overview.	Summarizes national statistics on lightning injuries.	Summarizes national statistics on lightning injuries.
2014	Costa, N., P. M. Arezes and R. B. Melo. 2014. "Effects of Occupational Vibration Exposure on Cognitive/Motor Performance." *International Journal of Industrial Ergonomics* 44(5):654-661.	Two different tests were selected and applied: an Action Judgment Test, which was primarily designed to examine the relation between the distribution of attention and the resultant reaction to ever-changing conditions, and an Omega Test, designed to examine the precision and attention in handling mechanisms. The results show that the vibration exposure level affects the degree of impairment. The subjects presented a lower performance level when exposed to higher vibration levels, as the time required to correct their errors more than doubled.	Effects of whole body vibration on driving tasks involving fine motor continuous and attention.
2013	Courtney, T. K., S. K. Verma, W.-R. Chang, Y.-H. Huang, D. A. Lombardi, M. J. Brennan and M. J. Perry. 2013. "Perception of Slipperiness and Prospective Risk of Slipping at Work." *Occupational and Environmental Medicine* 70(1):35-40	This study examined the association between perception of slipperiness and the risk of slipping. Perceptions of slipperiness and the subsequent rate of slipping were strongly associated. These findings suggest that safety professionals, risk managers and employers could use aggregated worker perceptions of slipperiness to identify slipping hazards and, potentially, to assess intervention effectiveness.	Perception of ice/snow slipperiness affects risk of slipping.

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2004	Crebolder, J.M., and R.B. Sloan. 2004. "Determining the Effects of Eyewear Fogging on Visual Task Performance." *Applied Ergonomics* 35(4):371-381.	The study concluded that fogging of lenses has a significant effect on visual detection and the use of anti-fog coating is relatively effective. However, in environments where prolonged fogging occurs water droplets form on anti-fog coated lenses which disrupts visual performance in a manner similar to the fog it is trying to prevent.	Mitigations for humidity
2009	Daanen, H.A.M. 2009. Manual Performance Deterioration in the Cold Estimated Using the Wind Chill Equivalent Temperature. Industrial Health 2009, 47, 262-270.	The deterioration in manual performance appeared to be strongly dependent upon Wind Chill Equivalent Temperature (WCET) and the square root of exposure time.	Manual dexterity
2003	Daanen, H.A.M., E. van de Vliert, X. Huang. 2003. Driving performance in cold, warm, and thermoneutral environments. Applied Ergonomics 34:597-602.	Study examining hot, cold, or thermoneutral car environment and performance. Concluded that a thermoneutral temperature in a car enhances driving performance and may thus positively affect safety. Using manual climatic controls in hot or cold cars may interfere with the driving task.	Hot/Cold EC effects on driving performance (fine motor)
2014	Dang, V.N., et al. 2014. *International HRA Empirical Study – Phase 3 Report, Results from Comparing HRA Methods Predictions to Hammlab Simulator Data on Low Scenarios.* NUREG/IA-0216, Volume 3, Office Of Nuclear Regulatory Research, Washington, D.C. ML14358A254.	International HRA empirical study. USNRC; Paul Scherrer Institute, Switzerland; Sandia National Lab; Scientech; OECD Halden Reactor Project, Norway. Vol 1 - overall approach and pilot results from comparing HRA methods to simulator performance data. Vol 2 - comparing HRC predictions to simulator data from SGTR scenarios. Vol 3 - comparing HRC predictions to HAMMLAB simulator data on LOFW scenarios.	Background on HRA
1975	Davis, F. M., Baddeley, A. D., & Hancock, T. R. (1975). Diver performance: The effect of cold. Undersea Biomedical Research 2(3), 195-213.	Fifteen divers performed five tasks in water of temperatures 20 degrees C and 5 degrees C, using standard scuba equipment. A significant deterioration of performance occurred under the colder condition in: simple arithmetic 13%; logical reasoning 17%; word recall 37%; word recognition 11%; and manual dexterity 17%. Throughout each dive, rectal and five skin temperatures were monitored. Average fall in rectal temperature was 0.5 degrees C during 20 degrees C dives and 1.1 degrees C during 5 degrees C dives. Average body surface temperature fell by 5 degrees C and 12.5 degrees C respectively. Average heat losses calculated from the data were 95 kcal.m (-2).hr (-1) (20 degrees C dives) and 245 kcal.m (-2).hr (-1) (5 degrees C dives). The impairment in word recognition was significantly correlated with the fall in rectal temperature for the 5 degrees C dives. For other tests, the deterioration did not appear to be correlated with body-temperature changes, but rather, occurred rapidly upon cold water immersion. The significance of these findings is discussed in relation to current understanding of the mechanisms by which cold is thought to influence performance underwater.	Among mixed results studies of cold effect, this showed fairly consistent degradations in various memory abilities, including short-term memory recall. However, reasoning tends to show less straightforward results; albeit this showed a decrement.
1983	Davis, P. R. 1983. "Human factors contributing to slips, trip and falls." Ergonomics 26:51-59.	This paper attempts to review existing knowledge of some human factors contributing to slipping and falling. After considering the biomechanics of normal unladen locomotion, the effects of load carriage on stability are considered by extrapolation from a static model. Visual needs are then considered, including the importance of the optic flow field and of the perception of falling hazards. Finally some aspects of fatigue are presented. The need for considerable further research is indicated.	Holding a load adversely affects postural stability in rough proportion to its weight and height -- presenting an issue on snow, ice and other slippery surfaces.
1973	DDC (Defense Documentation Center). 1973. Environmental Pollution: Noise Pollution--Noise Effects on Human Performance. 769, The Center,	A bibliography of 254 citations for noise effects on human performance.	Bibliography of noise effects.
2012	Defense, D.o. 2012. "Department of Defense Design Criteria Standard" in Human Engineering, Vol MIL-STD-1472G.	This standard establishes general human engineering criteria for design and development of military systems, equipment, and facilities. The purpose of this standard is to present human engineering design criteria, principles, and practices to be applied in the design of systems, equipment, and facilities so as to: a. Achieve required performance by operator, control, and maintenance personnel. b. Achieve required manpower readiness for system performance. c. Achieve required reliability of personnel-equipment combinations. d. Foster design standardization within and among systems.	Provides engineering criteria for human factors in DoD systems.
2008	Denissen, J. J. A., Butalid, L., Penke, L., and van Aken, M. A. G. 2008. The Effects of Weather on Daily Mood: A Multilevel Approach. Emotion 8:662-667.	Examines the effects of six weather parameters (temperature, wind power, sunlight, precipitation, air pressure, and photoperiod) on mood (positive affect, negative affect, and tiredness).The results revealed main effects of temperature, wind power, and sunlight on negative affect. Sunlight had a main effect on tiredness and mediated the effects of precipitation and air pressure on tiredness. In terms of explained variance, however, the average effect of weather on mood was only small.	Effects of Heat/Cold/Precipitation/Light on mood
1989	Departments of the Army and Air Force. Weather Support For Army Tactical Operations. FM34-81 / AFM 105-4	Provides support for combat operations through using the weather as an advantage.	Discusses skillful integration of weather in military planning and execution of combat
2010	Dobbins, T., J. Stark, S. Myers, and G. Mantzouris. 2010. Modelling Human Performance in Maritime Interdiction Operations. DTIC Document.	The maritime environment is arguably one of the harshest work environment in which humans must contend. In addition to either extremes of temperature, the repeated shock and vibration exposure of the high speed craft has been shown to result in high levels of post-transit fatigue which potentially reduces operational effectiveness during subsequent operational phases. This paper describes an example military operation, the development of a methodology to assess performance degradation via an operationally specific test battery, the qualification of high speed craft motion and shock mitigation, the results of assessing post-transit fatigue and issues of objectively assessing target prosecution.	Naturalistic examination of Heat/Cold/Vibration effects on performance in military operations
2013	Doherty, V., D. Croft, and A. Knight. 2013. "Environmental Information for Military Planning." Applied Ergonomics 44(4):595-602. http://www.sciencedirect.com/science/article/pii/S000368 7012001883.	The aim of the study was to use human factors and cognition expertise, and a user-centered design approach to:-consider techniques for presentation of environmental information(EI);-present guidance for ensuring EI data usability; and-create a paper-based mock-up of an HMI solution concept. The underpinning drivers for this study were:-improving user comprehension and situation awareness for environmental information; and-optimizing the interaction to enhance usability.	Focus is on presentation of environmental information, however may provide value in identifying environmental information of interest

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1981	Dornic, S. and S.E. Fernaeus. 1981. Type of processing in high-load tasks: The differential effect of noise. Report No. 576, Department of Psychology, University of Stockholm, Sweden.		
2003	Douris, P., R. McKenna, K. Madigan, B. Cesarski, R. Costiera, and M. Lu. 2003. "Recovery of Maximal Isometric Grip Strength Following Cold Immersion." Journal of strength and conditioning research / National Strength & Conditioning Association 17(3):509-513.	The purpose of this study was to investigate the effects of various cold immersion durations on maximal grip strength and the subsequent recovery of grip strength. Sixteen healthy men between 20 and 42 years of age participated in this study. Maximal isometric grip strength was measured before, immediately after, and 5, 10, and 15 minutes after cold immersion. Subjects submerged their dominant elbow, forearm, and hand in a cold water whirlpool at 10 degrees C for 5, 10, 15, or 20 minutes. There was a significant decrease in isometric grip strength when the forearm was immersed in 10 degrees C water for durations between 5 and 20 minutes and no recovery of this strength loss for a period of 15 minutes following removal from the cold immersion ($p = 0.0001$). These findings suggest that clinicians should be aware of the alterations in isometric muscle strength that result from utilizing the temperature and time frames of cold application used in this study.	
2013	Dovan, M. L. 2013. Examining the Effects of Anxiety on Running Efficiency in a Cognitive-motor Dual-task. Master of Science dissertation, Concordia University. Montreal, Quebec, Canada. http://spectrum.library.concordia.ca/977772/1/DovanML_4167023_MScThesis_A.pdf.	Study demonstrating that While broadly enhancing gross flight-fight performances (e.g., strength), a high level of arousal also interferes with performances involving complex skills, fine muscle movements, coordination, steadiness, and general concentration.	Effects of Lighting on arousal and cognitive and gross motor effects
1990	Driskell, J.E., B. Mullen, and C.L. Batchelor. 1990. Development of a Meta-Analytic Technique to Assess Stress Effects. DTIC Document.	This paper describes the use of a meta-analytic technique to identify the stress factors that restrict or limit effective performance. Preliminary analyses examining the effects of time pressure, group pressure, and noise on performance are presented.	Effects of noise on performance accuracy, performance speed, physiological effects, and psychological effects
1992	Ducharme M.B. and P. Tikuisis. 1992. "Forearm Temperature Profile during the Transient Phase of Thermal Stress." *European Journal of Applied Physiology* 64:395-401	Temperature response of the resting human forearm immersed in water at temperatures (Tw) ranging from 15 to 36°C was investigated. The data of the present study suggest that the forearm blood flow is an important determinant of the transient thermal response of the forearm tissue during thermal stress.	Mechanism of action for Cold effects on fine motor actions
1996	Dukes-Dobos, F.N., and T.E. Bernard. 1996. "Problematic Issues in Prevention of Injuries and Illnesses Resulting from Exposure to Heat and Cold Stress." *Applied Occupational and Environmental Hygiene* 11(4):282-287. http://dx.doi.org/10.1080/1047322X.1996.10389324.	Recommendations on methods to assess heat/cold stress include qualitative and quantitative task analysis, depending on the degree of accuracy required.	Potential framework for quantifying human performance impacts from environmental stressors
1989	Dupuis, H. 1989. Biodynamic behavior of the trunk and the abdomen during whole-body vibration. Acta Anaesthesiologica Scandinavica, 33: 34–38. doi:10.1111/j.1399-6576.1989.tb03001.x	Biomechanical models and experimental method/results are presented describing the effects of whole body vibration on the trunk and abdomen. Resonance and frequency are found to be important for effects.	Mechanism of action for Vibration effects
1966	Durnin, J., Haisman, M., Peters, D., and Zurick, L. 1966. The Effects of Hot Environments on the Energy Metabolism of Men Performing Standardized Physical Work. Army Personnel Research Establishment. Memo N/3.		
1957	Dusek, E. R. (1957). Effect of temperature on manual performance. In F. R. Fisher (Ed.), Protection and Functioning of the Hands in Cold Climates (pp. 63-76). Washington, DC: National Academy of Sciences, National Research Council.		
2005	Dyre, B. P., and Lew, R. 2005. Steering Errors may Result from Non-rigid Transparent Optical Flow. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 49(17):1531-1534.	Transparent, non-rigid optical flow can result from environmental factors (e.g., wind-blown snow) or technological factors (e.g., superposition of sensor imagery flow on the environmental flow viewed directly through the windscreen) and can produce systematic errors in judgments of the direction of heading and control of yaw. A pattern of systematic steering errors was found that suggests that motion transparency occurring in more realistic simulations can introduce systematic errors in controlling vehicles.	Mechanism of action for Snow effects on driving performance
2002	Echeverria, D, Heyer, N. J., Bittner, A. C., Jr., Rohlman, D., & Woods, J. S. (2002). Test-retest reliability and factor stability of the Behavioral Evaluation for Epidemiology Studies (BEES) Test Battery. Perceptual and Motor Skills, 95, 845-867.	The Behavioral Evaluation for Epidemiology Studies test battery uses touch-screen technology and novel methodologies to enhance neurobehavioral assessment. Scores generally show differential stability from the first trial with individual test reliabilities at or above .80 when normalized to a 3-min. administration. Six highly reliable ($r \geq .87$) factors were identified that cover functions known to be sensitive to neurotoxicants and physical exposures. These results strongly support recommendation of the new test battery for use in repeated-measures epidemiologic studies where first trial stability is desired.	

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1994	Echeverria, D., V. Barnes, A. Bittner, N. Durbin, J. Fawcett-Long, C. Moore, A. Slavich, B. Terrill, C. Westra, D. Wieringa, R. Wilson, D. Draper, D. Morisseau, and J. Persensky. 1994. *The Impact of Environmental Conditions on Human Performance, a Critical Review of the Literature.* NUREG/CR-5680, Volume 2, Pacific Northwest Laboratory, Richland, Washington. ML071210164.	Discussion of environmental conditions leading to performance impacts in nuclear power plant control rooms.	Baseline document for building upon environmental factors literature review.
1994	Echeverria, D., V. Barnes, A. Bittner, N. Durbin, J. Fawcett-Long, C. Moore, A. Slavich, B. Terrill, C. Westra, D. Wieringa, R. Wilson, D. Draper, D. Morisseau, and J. Persensky. 1994. *The Impact of Environmental Conditions on Human Performance, a Handbook of Environmental Exposures.* NUREG/CR-5680, Volume 1, Pacific Northwest Laboratory, Richland, Washington. ML070460030.	Outlines environmental conditions leading to performance impacts in nuclear power plant control rooms.	Baseline document for building upon environmental factors literature review.
2014	Edwards, B. D., Franco-Watkins, A. M., Cullen, K. L., Howell, J. W., & Acuff Jr, R. E. (2014). Unifying the challenge-hindrance and sociocognitive models of stress. International Journal of Stress Management, 21(2), 162.	We put forth a theoretical unification of 2 of the more popular theories of job stress: challenge-hindrance and the sociocognitive models of stress, to explain the process by which stress impacts performance. In Study 1, we manipulated challenge (n = 98) and hindrance stress (n = 96) and measured its effect on perceived stress, on-task effort, negative affective thoughts, and decision-making performance. The relationship between perceived stress and performance was fully mediated by on-task effort and negative affective thoughts. In Study 2, we manipulated stressor strength by randomly assigning participants to a pervasive time pressure (n = 48) or no time pressure (n = 47) condition. Compared with the no time pressure condition, the pervasive time pressure significantly reduced performance and increased perceived stress. Across the 2 studies, we identified a boundary condition of the challenge-hindrance model in that the severity of the stressor influenced the extent to which people perceive a stressor as a challenge or a hindrance and relationships with performance. Furthermore, individual differences in perceived stress had a stronger impact on performance than the actual stressors in the weaker situation (no time pressure). Our results demonstrate the advantage of uniting the sociocognitive model of stress with its emphasis on individual differences in stress perceptions with the challenge-hindrance model and its distinction between positive and negative stressors.	
1988	Edwards, J. B. 1988. The Relationship between Road Accident Severity and Recorded Weather. Journal of Safety Research 29:249-262.	This article investigates the relationship between weather and road accidents. The weather information recorded on Police Accident Report Forms was taken as the prevailing weather at the time of the accident. At the local authority level, accident severity for the various adverse weather categories of rain, fog, and high winds is compared with the nonhazardous condition of fine weather. Severity ratios are then calculated. Findings establish that accident severity decreases significantly in rain compared with fine weather, while severity in fog shows geographical variation.	Counterintuitive finding that accident severity decreases in Precipitation conditions
2002	Edwards, L., and Torcellini, P. 2002. A Literature Review of the Effects of Natural Light on Building Occupants. National Renewable Energy Laboratory, Golden, CO.	This paper summarizes the benefits that different wavelengths of light have on building occupants. Daylighting has been associated with higher productivity, lower absenteeism, fewer errors or defects in products, positive attitudes, reduced fatigue, and reduced eyestrain.	This mechanism – light enhanced reduction in melatonin and subsequent increase in alertness -- may be partly responsible for the observed improvements in worker performance demonstrated with natural and full-spectrum office lighting.
2004	Eisenberg, D. 2004. The Mixed Effects of Precipitation on Traffic Crashes. Accident Analysis and Prevention 336:637-647.	This paper investigates the relationship between precipitation and traffic crashes in the US during the period 1975-2000. Traffic crashes represent the leading cause of death and injury for young adults in the US, and the ninth leading cause of death for the overall population. Prior studies have found that precipitation raises the risk of traffic crashes significantly. A negative binomial regression approach is employed. Two different units of analysis are examined: state-months and state-days. The sample includes all 48 contiguous states.	First report of fatality reduction in precipitation though accident increase
2005	Eisenberg, D., and K. E. Warner. 2005. Effects of Snowfalls on Motor Vehicle Collisions, Injuries, and Fatalities. American Journal of Public Health 95:120-124.	We estimated the effects of snowfalls on US traffic crash rates between 1975 and 2000. Methods. We linked all recorded fatal crashes (1.4 million) for the 48 contiguous states from 1975 through 2000 to daily state weather data. For a subsample including 17 states during the 1990s, we also linked all recorded property-damage-only crashes (22.9 million) and nonfatal-injury crashes (13.5 million) to daily weather data. Employing negative binomial regressions, we investigated the effects of snowfall on crash counts. Fixed effects and other controls were included to address potential confounders.	Reports that -- though accidents increase with precipitation -- fatalities decrease arguably as slower speeds of collision
1987	Enander, A. E. (1987). Effects of moderate cold on performance of psychomotor and cognitive tasks. Ergonomics 30(10), 1431-1445.	Two experiments were performed to study the effects of exposure to moderate cold (+ 5°C) on psychomotor and cognitive tasks requiring sustained attention. Twelve male and 12 female subjects participated. Skin and core temperatures, heart rate and subjective ratings were recorded. Considerable decrements in manual dexterity were found during exposure, but no effects on simple reaction time or speed of correct response were observed. The effects of cold on the performance of complex tasks were demonstrated as an increase in the number of errors and the speed of incorrect response and as an increase in the number of false alarms on two computerized performance tests. The results, indicating a negative	
1989	Enander, A.E. 1989. "Effects of Thermal Stress on Human Performance." *Scandinavian Journal of Work, Environment and Health 15*(Suppl 1):27-33.	Experimental evidence indicates that even relatively mild thermal stress may affect human performance. Tasks requiring manual dexterity and muscular strength are clearly impaired by cold exposure, while decrements in vigilance performance and endurance are well documented effects of heat stress. Literature review	Thermal stress impacts on performance

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1990	Enander, A.E., and Hygge, S. 1990. Thermal Stress and Human Performance. Scandinavian Journal of Work Environmental Health 16(suppl 1):44-50.	There is evidence that the thermal stress encountered in many work environments may negatively affect various aspects of human performance and behavior. Evaluation of the empirical research is, however, complicated by differences in both the methodology and the definition of the basic stimulus. Effects of heat and cold stress are briefly reviewed, with particular regard to theoretical considerations.	
2004	EnHealth Council. 2004. The Health Effects of Environmental Noise- Other Than Hearing Loss. Department of Health and Ageing, Commonwealth of Australia, Canberra, Australia. https://docs.wind-watch.org/enHealth-2004-health-effects-noise.pdf.	Book describing the health effects of environmental noise	Health & safety results of environmental noise
1973	EPA (U.S. Environmental Protection Agency). 1973. Public health and welfare criteria for noise. Washington, DC.	1973 EPA noise criteria	outdated
1992	EPRI (Electric Power Research Institute). 1992. *Sharp1—a Revised Systematic Human Action Reliability Procedure.* EPRI TR-101711-T1, Palo Alto, California.	Sharp tool provided human performance reliability framework	Creating a new sharp1 tool to provide human performance reliability framework as part of a probabilistic risk assessment
2004	Evans, G.W., and Cohen, S. 2004. Environmental Stress	Tested different noise levels vs. unsolvable puzzle to see number of attempts. Also used dummy fixes to see if attempts increased.	Noise level will decrease work level.
2000	Evans, G.W., and Johnson, D. 2000. Environmental Stress	Open-office noise elevated stress levels and ability to perform tasks.	Performance is hampered even with very low background noise levels.
2012	Exelon Generation. 2012. "Letter from G.T. Kaegi to NRC, Dated November 27, 2012, Regarding "Exelon Generation Company, Llc's 180-Day Response to NRC Request for Information Pursuant to 10 CFR 50.54(F) Regarding the Flooding Aspects of Recommendation 2.3 of the near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident."." ML12332A305.		
2013	Fernando, Ana Catarina Rocha Mendes, Helder Manuel Arsénio Lopes, António Manuel Neves Vicente, João Filipe Pereira Nunes Prudente, and Roland van den Tillaar. 2013. "Effects of Cold Rainy Weather vs. Normal Warm Indoor Environment upon Cognitive Performances." International Journal of Humanities and Social Science 3(17):28-33.	In education we also have to consider the performances obtained and the conditions where they are obtained. 'Preparing for life' is about having knowledge and, sometimes, being able to use it in difficult conditions. Traditional classroom can be occasionally misguiding, but through sport it's possible to understand phenomena that can be transferred to education. The aim of our study was to investigate the influence of cold and rain in outdoor sports on the cognitive performances of amateur hikers. Cognitive performance of 40 amateur hikers was tested (arithmetical operations test) in a comfortable surrounding with mild temperature and outdoors on a rainy and mildly windy day. Significant differences in the time to solve the test was found in different environments ($p<0.0001$), taking longer outdoors, as well as the number of faults ($p<0.0001$). We can conclude that even a mild change in weather environment can influence the cognitive performance.	Demonstrated arithmetic performance in wet-rain conditions vs indoor, but nature of effect is unclear
2005	Fewell, M., and M.G. Hazen. 2005. "Cognitive Issues in Modelling Network-Centric Command and Control."	Discussion of military decision making models	Relevant to IMPRINT modelling approach
2004	FHWA (Federal Highway Administration). 2004. Identifying and Assessing Key Weather-Related Parameters and Their Impacts on Traffic Operations Using Simulation. FHWA-HRT-	Simulation results for effects of weather on traffic speed	Precipitation, Ice/Snow effects on driving performance at the group level
2014	FPL (Florida Power and Light). 2014. "Letter from J. Jensen to NRC, Dated May 12, 2014, Regarding "St. Lucie Units 1 and 2, Reportable Event: 2012-010, Date of Event:		
2002	French, J. 2002. "A Model to Predict Fatigue Degraded Performance." in Human Factors and Power Plants, 2002. Proceedings of the 2002 IEEE 7th Conference on, pp. 46-49.	Empirically based mathematical algorithm was developed for a tool that can be used to manage fatigue on duty. The algorithm estimates fatigue resulting from extended duty days and fragmented or reduced sleep. It was validated by predicting the observed outcome from a separate study of performance degradation by fatigue.	Human performance degradation from fatigue
1995	Fridstrom, L., Liver, J., Ingebrigsten, S., Kulmala, R., & Thomsen, L. 1995. Measuring the Contribution of Randomness, Exposure, Weather, and Daylight to the Variation in Road Accident Counts. Crash Analysis and Prevention 27:1-20.	Using a generalized Poisson regression model, the variation in accident counts was decomposed into parts attributable to randomness, exposure, weather, daylight, or changing reporting routines and speed limits. Pure randomness explained a major part of the variation in smaller accident counts (e.g. fatal accidents per county per month), while exposure is the dominant systematic determinant. Together, randomness and exposure account for 80% to 90% of the observable variation. A surprisingly large share of the variation in road casualty counts is thus explicable in terms of factors not ordinarily within the realm of traffic safety policy.	Effects of Precipitation and Ice/Snow on accidents are relatively small compared to other factors.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1967	Gagge, A. P., Stolwijk, J. A., & Hardy, J. D. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Environmental Research I: 1-20.	Sensory estimates of comfort and thermal sensation for resting-sitting unclothed subjects have been compared with the associated physiological responses for the range of ambient temperatures (12°–48°C) under steady-state and transient conditions. For steady exposure to cold and warm environments, thermal comfort and neutral temperature sensations lie in the range for physiological thermal neutrality (28°–30°C), in which there is no physiological temperature regulatory effort. Discomfort increases more rapidly below 28°C than above 30°C, while thermal sensation for both heat and cold increases rapidly each side of neutral. Discomfort correlates best with lowering average skin temperature toward cold environments and with increased sweating toward hot environments. In general, discomfort is associated with a change of average body temperature from 36.5°C. The same conclusion follows for transient changes when the subject goes from comfortable to uncomfortable, neutral to cold, and neutral to warm. When these transients are reversed (i.e., cold to neutral, hot to neutral), the sensations of comfort and temperature “lead” the body temperature changes and are thus “anticipatory.” This hysteresis effect is most striking in the cold and less so for warmth. For transients from cold to warm, the rate of rise of skin temperature causes a sensation that compensates for and predominates over the sensation of discomfort caused by a low skin temperature itself. Finally, thermal discomfort is an excellent stimulus for behavioral activity by man. As a sensation, it gives man both an early and anticipatory drive for conscious action that may effect changes in his body's microclimate rather than having him depend on natural but short-term means of thermal protection—sweating, vasodilation, vasoconstriction and shivering.	Supporting psychological explanations for cold's effects on performance (discomfort affects performance, before core temp. begins to drop), this is one of several studies suggest that the temperature of extremities (hands and feet) is particularly important to the experience of discomfort. As temperature declines, workers tend to experience the least discomfort just after the point when cold extremities have signaled the brain to engage adaptive heat production and/or conservation.
2008	Gao, C., I. Holmér, and J. Abeysekera. 2008. "Slips and Falls in a Cold Climate: Underfoot Surface, Footwear Design and Worker Preferences for Preventive Measures." Applied Ergonomics 39(3):385-391.	Describes the consequences of slips and falls on ice and snow and the associated injuries, and assesses the risks of various icy and snowy surfaces, to identify design needs of footwear, and to ascertain preventive measure preferences of outdoor workers. The results showed that fall events occur most frequently on ice covered with snow. This is due to the difficulty of perceiving hidden risks in order to adjust gait strategies. The professional footwear provided does not provide enough protection against slips and falls. Slip resistant properties are ranked as one of the top requirements by the users. Their most preferred preventive measures are footwear with anti-slip properties and the application of anti-slip materials, such as sand or salt.	Ice/Snow slip mitigation and causes.
2010	Gaoua, N. 2010. “Cognitive Function in Hot Environments: Aquestion of Methodology.” *Scandinavian Journal of Medical Science and Sports* 20:60-70.	This article gives an overview of the different confounding factors that have made it difficult to make conclusive interpretations about the effects on performance. In addition, the current state of knowledge is presented and discussed with reference to the Global Workspace theory. Although previously presented conclusions are promising, much remains to be completed before understanding the mechanisms that could explain the relationship between heat exposure and cognitive function.	Methodological differences account for equivocal relationships between Heat and cognitive performance findings.
2012	Gaoua, N., J. Grantham, S. Racinais, and F. El Massioui. 2012. “Sensory Displeasure Reduces Complex Cognitive Performance in the Heat.” *Journal of Environmental Psychology* 32:158-163	The physiological responses of thermal stress and its consequences on health have been well documented. However, the effect on cognitive function remains equivocal despite a substantial number of studies conducted in the area. Methodological discrepancies across different studies have made it difficult to conclude whether or not heat exposure per se has an adverse effect upon cognitive function and under what specific environmental and physiological conditions these alterations appear. This article gives an overview of the different confounding factors that have made it difficult to make conclusive interpretations. In addition, the current state of knowledge is presented and discussed with reference to the Global Workspace theory. Although previously presented conclusions are promising, much remains to be completed before understanding the mechanisms that could explain the relationship between heat exposure and cognitive function. Finally, recommendations are presented for Further research in this area.	Demonstrates that sensory displeasure (discomfort) reduces cognitive performance in heat prior to hyperthermic domain
1971	Gardinier, C.A. 1971. *A Study of the Effects of Illumination and Noise on Simple Motor Performance.* AD 739474, U.S. Army Materiel Command Intern Training Center, Texarkana, Texas.	Study investigates the effects of two environmental stressors, illumination and noise, on human performance	Model for combining performance effects from two environmental stressors
2014	Garg, A., Boda, S., Hegmann, K.T., Moore, J.S., Kapellusch, J.M., Bhoyar, P., Thiese, M.S., Merryweather, A., Deckow-Schaefer, G., Bloswick, D., Malloy, E.J. The NIOSH Lifting Equation and Low-Back Pain, Part 1: Assoc With Low-Back Pain in the BackWorks Prospective Cohort Study. Human Factors. Vol. 56, No. 1, February 2014, pp. 6 –28	Evaluated relationships between the revised NIOSH lifting equation (RNLE) and risk of low-back pain (LBP).	Job physical stressors are associated with increased risk of LBP. Data suggest the peak lifting index and peak composite lifting index are useful metrics for estimating exposure to job physical stressors
2014	Garg, A., Boda, S., Hegmann, K.T., Moore, J.S., Kapellusch, J.M., Bhoyar, P., Thiese, M.S., Merryweather, A., Deckow-Schaefer, G., Bloswick, D., Malloy, E.J. The NIOSH Lifting Equation and Low-Back Pain, Part 2: Assoc With Low-Back Pain in the BackWorks Prospective Cohort Study. Human Factors. Vol. 56, No. 1, February 2014, pp. 44 –57	Investigate the relationship between the revised NIOSH lifting equation (RNLE) and risk of seeking care for low-back pain (SC-LBP).	Job physical stressors are associated with increased risk of SC-LBP. Data suggest that both the PLI and PCLI are useful metrics for estimating exposure to job physical stressors.
2009	Garrett, J., and J. Teizer. 2009. "Human Factors Analysis Classification System Relating to Human Error Awareness Taxonomy in Construction Safety." Journal of Construction Engineering and Management 135(8):754-763. http://dx.doi.org/10.1061/ (ASCE)CO.1943-7862.0000034.	In several studies it is widely accepted that human error is the main reason for up to 80% of all incidents and accidents in complex high-risk systems that exist in the aviation, petrochemical, healthcare, construction, mining, and nuclear power industries. The construction industry, greatly impacted by accidents, is accountable for more than 1,000 fatalities in each of the past 14 years. The human factors analysis classification system (HFACS) is a general human error framework originally developed and tested as a tool for investigating and analyzing the human causes of accidents with applications to rail, air, and offshore environments. This paper introduces the concept of HFACS along with the framework of human error awareness training (HEAT) and their potential contribution to the construction industry. Based on the HEAT approach, this paper proposes a new error analysis educational and classification tool for safety within the construction industry. The primary difference between HFACS and HEAT is found in the structure, content, and presentation of the information allowing for higher effectiveness in incident investigation and safety education and training in construction. - See more at: http://ascelibrary.org/doi/abs/10.1061/(ASCE)CO.1943- 7862.0000034#sthash.KFDz5ZVb.dpuf	

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2008	Gawron, V. 2008. Human Performance, Workload, and Situational Awareness Measure Handbook. Boca Raton, FL: CRC Press.	Human performance measurement is the cornerstone of human factors and experimental psychology and the Human Performance Measures Handbook has long been its foundational reference. Reflecting a wider range and scope, the second edition, newly named Human Performance, Workload, and Situational Awareness Measures Handbook, presents changes in the field and increased applications. It covers the basics of measurement and provides authoritative summaries of over 100 performance, workload, and situational awareness (SA) measures. It contains evaluations of metrics drawn from an extensive literature review and from hundreds of actual projects, grounding research with real-world applicability. The book also defines workload; provides performance, subjective, simulation, and psychological measures; and gives guidance on how to select the right workload measure. The author rounds out the coverage by presenting four types of measures for SA: subjective, observational, physiological, and measures of SA ability. What's New Additional measures of team performance Expanded glossary includes terms added to the discipline over the last 7 years Updated information from various journals including Ergonomics and Aviation, Space, and Environmental Medicine	
2011	Giguere, C., C. Laroche, A. J. Brammer, V. Vaillancourt, G. Yu. 2011. Advanced Hearing Protection And Communication: Progress And Challenges. 10th International Congress on Noise as a Public Health Problem (ICBEN), At London, UK, Volume: Proceedings of the Institute of Acoustics 33 (Pt.3), 225-233	Review of state of the art noise mitigations.	Mitigations for Noise
1991	Giordano, L.A., J. Michael Fritsch. 1991. "Strong Tornadoes and Flash-Flood-Producing Rainstorms During the Warm Season in the Mid-Atlantic Region." *Weather and Forecasting* 6(4):19.	Storm-related literature spanning 45 years (1942-1986) was examined to 1) establish a climatology of strong tornadoes and intense rainstorms for the Mid-Atlantic region, and 2) identify the key environmental features that distinguish the days producing strong convective events.	Identify other potential environmental stressors associated with severe weather
1971	Givoni, B. and R.F. Goldman, R.F. 1971. Predicting metabolic energy cost. Journal of Applied Physiology, 30(3):429-433.	Supplementing original data on the energy costs of level or grade walking, with and without loads, with material from the literature, an empirical equation was prepared for prediction of the metabolic costs of such activities. The equation has been examined and found to be valid for walking speeds from 2.5 to 9 km/ h with grades up to 25% and running speeds from 8 to 17 km/h with grades up to 10% with loads up to 70 kg. Modifying coefficients are suggested for terrains other than treadmill walking, for load placement and for very heavy work. The correlation between predicted and measured energy costs is usually 0.95 or greater; the mean standard error of estimate over all conditions is 29 kcal/h. The equation also appears valid when the subject is free to choose his own progression rate.	
1999	González-Alonso, J., C. Teller, S. L. Andersen, F. B. Jensen, T. Hyldig, and B. Nielsen. 1999. "Influence of Body Temperature on the Development of Fatigue during Prolonged Exercise in the Heat." *Journal of Applied Physiology* 86:1032-1039.	Results demonstrate that high body temperature per se causes fatigue in trained subjects during prolonged exercise in uncompensable hot environments. Furthermore, time to exhaustion in hot environments in trained subjects is inversely related to the initial level of body temperature and directly related to the rate of heat storage.	Mechanism of action for Heat stress effects
1970	Grether, W.F. 1970. *Effects on Human Performance of Combined Environmental Stress*. AMRL-TR-70-68, Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio.	This paper presents a critical review of these past studies from the particular viewpoint of whether performance decrements from combined stresses are more severe than would be predicted from single stress studies.	Model for combining performance effects from two environmental stressors
1973	Grether, W.F. 1973. "Human Performance at Elevated Environmental Temperatures." *Aerospace Medicine* 44:747-755	A review of research on human performance at elevated temperatures is presented. The findings are analyzed in terms of 5 categories of performance measurements: time estimation; reaction time; vigilance and monitoring; tracking; and cognitive and other skilled tasks. Time estimation studies, requiring subjects to count or tap at specified rates, generally show increased speed of response with elevation of internal body temperature. Most studies of simple reaction time have also resulted in increased speed as either body or environmental temperatures are experimentally increased. Presumably both of these effects are a reflection of increased speed of neural conduction. Improvements in performance have also been found in measurements of vigilance, with optimum performance appearing at an Effective Temperature (ET) of about 80°F. For all other performance functions there appears to be a plateau, with only minor effects, up to an ET of about 85°F. As environmental temperatures exceed this value there are generally increasing performance decrements. This plateau up to 85°F ET appears to coincide very closely with the range over which the human body can compensate physiologically to elevated environmental temperatures.	
1972	Grether, W.F., & Baker, CA. (1972). Visual presentation of information in human engineering. In H.P. VanCott & R.G. Kincade (Eds.) Guide to _Equipment Design. Washington, DC: US. Government Printing Office.		
2012	Griffin, M. J. 2012. Handbook of human vibration. Elsevier, London, UK.	Today the human body is exposed to vibration not only while traveling but also during leisure and domestic activities and in many occupations. This volume summarizes the current understanding of the many human responses to vibration. Divided into two parts, this book deals with whole-body vibrations and hand-transmitted vibration. In each part the experimental data and appropriate models are presented in detail so that readers can address practical problems. An extensive guide to national and international standards is provided, and a large multidisciplinary glossary of terms assists in understanding the relevant technical and medical jargon.	

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1995	Grönqvist, R. 1995. Mechanisms of Friction and Assessment of Slip Resistance of New and Used Footwear Soles on Contaminated Floors. Ergonomics 38(2):224-241.	In the present study the influence of the normal wear of shoe heels and soles on their frictional properties was clarified. The slip resistance of three types of new and used safety shoes on four relatively slippery floor-contaminant combinations, was assessed with a prototype apparatus, which simulates the movements of a human foot and the forces applied to the underfoot surface during an actual slip.	Relevant to mechanism of action for Ice/Snow slippage
1999	Gronqvist, R. 1999. Chapter 12: Slips and Falls. In Biomechanics in Ergonomics, Kumar, S., Ed. Taylor and Francis: London.		
1994	Grönqvist, R., and Hirvonen, M. 1994. Pedestrian Safety on Icy Surfaces: Anti-Slip Properties of Footwear. In F. Aghazadeh (Ed.) Advances in Industrial Ergonomics and Safety VI, London: Taylor and Francis, 315-322.		
1995	Grönqvist, R., and Hirvonen, M. 1995. Slipperiness of Footwear and Mechanisms of Walking Friction on Icy Surfaces. International Journal of Industrial Ergonomics 16(3):191-200.	The coefficient of kinetic friction of 49 types of footwear was determined using a prototype apparatus simulating actual foot slippage on dry and wet smooth ice at surface temperatures of - 10 ° C and 0 ° C, respectively. The effects of soling material type, hardness, and tread design on the frictional properties were assessed in particular. In addition the effect of strewing sand on ice was studied. The properties of ice had the greatest influence on the coefficient of kinetic friction, and hence, slip resistance. Of the assessed footwear, over 90% was classified as very slippery on wet ice, and 60% as slippery on dry ice.	Mechanism of action for slippage on ice/snow
2001	Grönqvist, R., Chang W. R., Courtney, T. K., Leamon, T. B., Redfern, M. S., Strandberg, L. 2001. Measurement of Slipperiness: Fundamental Concepts and Definitions. Ergonomics 44(13):1102-1117.	Gives an overview of basic concepts and definitions of terms related to the 'measurement of slipperiness' from the onset of a foot slide to a gradual loss of balance and a fall.	Mechanism of action for slippage on ice/snow
1982	Guignard, J. C., Bittner Jr, A. C., & Carter, R. C. (1982). Methodological investigation of vibration effects on performance of three tasks. Journal of Low Frequency Noise, Vibration and Active Control, 1(1), 12-18.	Twenty young Naval enlisted male volunteers were first rehearsed and then tested before, during, and after vertical (z-axis) whole-body vibration. Fourteen were tested only at 8 Hz, and six were tested at 8 Hz/0.21 gz rms, 16 Hz/0.43 gz rms and 32 Hz/0.85 gz rms, using three paper-and-pencil tasks involving visual, motor, and cognitive skills. The tasks were 'Spoke', a speed of tapping test; "Aiming", a test of fine motor coordination; and "Coding", involving mental computation. Results showed an approximately equal decrement across conditions in the Spoke and Coding (but not Aiming) tests that conforms with the frequency function embodied in the current international standard (ISO 2631–1978) on human exposure to vibration. In addition, it was found that a modicum of vibration experience may be necessary before reliable data are obtained in this kind of testing. Implications for methodology and for the application of the current standard are briefly discussed.	
2014	Haas, E.C., H.P. Crowell, and K.L. Kehring. 2014. *The Effect of Physical Load and Environment on Soldier Performance.* ARL-TR-6842, Army Research Laboratory, Aberdeen Proving Ground, Maryland.	A study was conducted to characterize the interaction between physical load and environment on dismounted Soldier performance in navigation and auditory vigilance tasks	Applicability to performance and various manual actions (lifting, carrying etc.)
1991	Hackney, A., J. Shaw, J. Hodgdon, J. Coyne, and D. Kelleher. 1991. "Cold Exposure During Military Operations: Effects on Anaerobic Performance." Journal of Applied Physiology 71(1):125-130.	This study examined the effects of military field operations (MFO) under different environmental conditions on anaerobic performance. (ANP). U. S. Marines were tested in the field under the following conditions: 1) non-cold environment (NC; n-30, 10 to 320 C), and 2) a cold environment (GO; n=32, -2 to -220C). Subjects performed 30 sec Wingate tests (WIN), 2 min push-ups, and hand- grip strength. Reductions occurred in absolute MP (651.8±30.3 to 616.4±28.5 W; X+SE) and PP (897.8±41.6 to 857.0±39.1 W); however, no effect on Fl was seen. Significant interaction effects (p<0.05) were observed in relative measures.	Cold vs baseline environment effects on gross motor skills
1988	Haisman, M.F. Determinants of load carrying. Applied Ergonomics 1988, 19.2, 111 - 121	Studied load carrying ability. Determinants of load carriage ability include age, anthropometry, aerobic and anaerobic power, muscle strength, body composition and gender; other relevant factors are the subjective effects perceived during load carriage, the dimensions and placement of the load, biomechanical factors, nature of the terrain and the gradient, the effect of climate and protective clothing.	No definition of max load, due to widely varying circumstances that may apply. Healthy young males there is a rule of thumb of one-third body weight, or relative work load equivalent to one-third of the VO2 max for a working day.
2006	Hallbert, B., R. Boring, D. Gertman, D. Dudenhoeffer, A. Whaley, J. Marble, J. Joe, and E. Lois. 2006. *Human Event Repository and Analysis (Hera) System, Overview.* NUREG/CR-6903, Volume 1, Idaho National Laboratory, Idaho Falls, Idaho. ML062700593.	The Idaho National Laboratory (INL), sponsored by the Nuclear Regulatory Commission, has developed a repository entitled Human Event Repository and Analysis (HERA). The objective of HERA is to make available empirical and experimental human performance data, from commercial nuclear power plants (NPPs) and other related technologies, in a content and format suitable to human reliability analysis (HRA) and human factors practitioners. This Volume 1 of NUREG/CR-6903, discusses the need for a systematic collection of human performance data on the basis of current regulatory HRA and human factors applications, describes the taxonomy and structure of the data in HERA, and presents examples of information extraction and coding.	
2006	Hallbert, B.P., D.D. Dudenhoeffer, L.G. Blackwood, K. Hansen, S. Mahadevan, J. Wreathall. 2006. Developing Human Performance Measures: Project Mileston Deliverable Letter Report. Idaho National Laboratory, Idaho Falls, ID.	This report reviews the large body of empirical knowledge and data that define the current state of knowledge and development in human performance and begins to begin to develop quantitative models of nuclear power plant operations. It presents an approach for establishing the technical basis for the development of human performance measures that has four components: a review of modeling standards and criteria; an assessment of past and current industry measures and practices used for human performance monitoring; the evaluation of historical plant performance data against human performance data; and finally, the application of modeling and simulation techniques to examine and evaluate proposed performance measures.	

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2006	Hancock P. A., G.E. Conway, J.L. Szalma, J.M. Ross, and B.M. Saxton. 2005. A meta-analysis of noise effects on operator performance for IMPRINT. (Technical Report DAAD-19-01-C-0065, UCFMIT-ARL-05-01). Orlando, FL.	Noise is pervasive and influential source of stress, whether acute or chronic. Noise effects upon various forms of cognitive and physical response. Quantitative evaluation of influences so most harmful effects can be mitigated, most beneficial effects exploited and residual effects incorporated and synthesized into selection, training and design strategies to facilitate mission operations. Surveyed 423 papers, reports, and accounts to 506 effect sizes from 179 studies. Derived effects were subjected to meta-analysis.	Noise acts to degrade goal-directed behavior, especially when the emphasis is on accurate performance and features central (cognitive) processing.
1986	Hancock PA (1986). Sustained attention under thermal stress. Psych Bull, 99, 63-281.	This article reviews the effects of the thermal environment on vigilance. A reinterpretation of early and contemporary studies contradicts the existing notion that vigilance is facilitated in ambient temperatures that exceed a comfortable level. Rather, performance is degraded as thermal homeostasis of the observer is disturbed. Significant breakdown in capability becomes manifest with measurable perturbation to deep body temperature. This assertion requires that conditions induce a dynamic change, as performance is unaffected with no variation in deep body temperature and is facilitated when the observer is established in a static hyperthermic state. An attentional account of this phenomenon is offered, which contrasts with previous arousal explanations	
1998	Hancock, P.A., and I. Vasmatzidis. 1998. "Human Occupational and Performance Limits under Stress: The Thermal Environment as a Prototypical Example." *Ergonomics* 41(8):1169-1191.	Authors contend that task performance level should be the primary criterion for thermal exposure.	Performance based measures of exposure
2003	Hancock, P.A., and I. Vasmatzidis. 2003. "Effects of Heat Stress on Cognitive Performance: The Current State of Knowledge." *International Journal of Hyperthermia* 19(3):355-372. Available at http://www.ncbi.nlm.nih.gov/pubmed/12745975.	This paper discusses the current state of knowledge on the effects of heat stress on cognitive performance.	Cognitive performance measures
2003	Hancock, P.A., and J.L. Weaver. 2003. "The Mitigation of Stress, Workload and Fatigue on the Electronic Battlefield." *Operator Functional State,* G.R.J. Hockey, Gaillard, W.W.K, Burov, O., pp. 53-64. IOS Press,	White paper categorizes the sources of physical and cognitive stress imposed on infantry personnel and explores principled bases for the mitigation of such sources of stress. The outcomes of the program to date are surveyed with an eye to performance on the emerging electronic battlefield. Discussed in terms of maximal adaptability model of stress.	IMPRINT background and stress effects on performance
2001	Hancock, P.A., and P.A. Desmond, Eds. 2001. Stress, workload, and fatigue. Lawrence Erlbaum, Mahwah, New Jersey.	Stress, Workload, and Fatigue is a collective text featuring the leading voices in each of these respective domains who provide insight concerning the present state-of-the-art in theory, research, and practice. The central theme is the commonality between each of the 3 facets of behavior, comprehension of which is crucial to the understanding and prediction of human behavior in all settings, especially the crucible of the real world. (PsycINFO Database Record (c) 2016 APA, all rights reserved)	
2005	Hancock, P.A., G.E. Conway, and J.L. Szalma. 2005. *A Meta-Analysis of Whole Body Vibration Effects on Soldier Performance for Imprint.* DAAD-19-01-C-0065. UCF-MIT2-ARL-05-02, University of Central Florida, Orlando, FL.	The present report is the second in a series of comprehensive meta-analyses which provide a quantified summary of existing research evidence on vibration effects in order to inform and improve IMPRINT.	IMPRINT background; vibration effects on performance
2005	Hancock, P.A., G.E. Conway, J.L. Szalma, J.M. Ross, and B.M. Saxton. 2005. A Meta-Analysis of Noise Effects on Operator Performance for Imprint. University of Central Florida, Orlando, FL.	Meta-analysis which provides a quantified summary of existing research evidence on noise effects in order to inform and improve IMPRINT.	IMPRINT background; noise effects on performance
2001	Hancock, P.A., H.C.N. Ganey, M. Mouloua, E. Salas, R. Gilson, A. Greenwood-Ericksen, R. Parasuraman, W. Harris, A. Leon, and K. Smith. 2001. "A Descriptive Framework for the Evaluation of Stress Effects on Operator Performance." Proceedings of the Human Factors and Ergonomics Society Annual Meeting Proceedings of the Human Factors and Ergonomics Society Annual Meeting 45(13):948-956.	Provides a general descriptive framework that relates the action of stress on operator performance capacity. By considering the commonalities of brain function with the response processes of other organs of the body, they use the extensive existing body of physiological insight to provide guiding principles to explore undoubtedly more complex cognitive responses to stress.	IMPRINT Background, especially stress mechanism of action for performance effects
2007	Hancock, P.A., J.M. Ross, and J.L. Szalma. 2007. "A Meta-Analysis of Performance Response under Thermal Stressors." *Human Factors* 49(5):851-877.	Authors attempt to quantify the effect of thermal stressors on human performance.	Thermal stress impacts on performance
2005	Hancock, P.A., J.M. Ross, T. Oron-Gilad, and J.L. Szalma. 2005. *The Incorporation of Comprehensive Thermal Stress Effects into Imprint.* DAAD-19-01-C-0065, UCF-MIT-ARL- 05-01, University of Central Florida, Orlando, RL.	Stress, Workload, and Fatigue is a collective text featuring the leading voices in each of these respective domains who provide insight concerning the present state-of-the-art in theory, research, and practice. The central theme is the commonality between each of the 3 facets of behavior, comprehension of which is crucial to the understanding and prediction of human behavior in all settings, especially the crucible of the real world. (PsycINFO Database Record (c) 2016 APA, all rights reserved)	
2002	Hancock, P.A., P. Ward, J.L. Szalma, S. Stafford, and H.C.N. Ganey. 2002. "Stress and Human Information Processing: A Descriptive Framework Presented in a Novel Manner." in 23rd Annual Army Science Conference, pp. 2. Orlando, FL.	Our framework describes a three dimensional matrix with types of information processing along the first dimension, stressors along the second, and moderators of the stress-performance relationship along the third. The purpose of the matrix is to provide a comprehensive review of the extant literature which will not only identify avenues for future research but will provide empirical support for addressing current models of soldier-system performance under stressful conditions.	IMPRINT Background, especially stress mechanism of action for performance effects

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1961	HARMON, F.L., and B.T. KING. 1961. Vulnerability of Human Performance in Communications. DTIC Document.	Stress, Workload, and Fatigue is a collective text featuring the leading voices in each of these respective domains who provide insight concerning the present state-of-the-art in theory, research, and practice. The central theme is the commonality between each of the 3 facets of behavior, comprehension of which is crucial to the understanding and prediction of human behavior in all settings, especially the crucible of the real world. (PsycINFO Database Record (c) 2016 APA, all rights reserved)	
2015	Harriott, C.E., G.L. Buford, J.A. Adams, and T. Zhang. 2015. "Mental Workload and Task Performance in Peer-Based Human-Robot Teams." *Journal of Human-Robot Interaction* 4(2):61-96.	Stress, Workload, and Fatigue is a collective text featuring the leading voices in each of these respective domains who provide insight concerning the present state-of-the-art in theory, research, and practice. The central theme is the commonality between each of the 3 facets of behavior, comprehension of which is crucial to the understanding and prediction of human behavior in all settings, especially the crucible of the real world. (PsycINFO Database Record (c) 2016 APA, all rights reserved)	
1989	Harris, R. M., Hill, S. G., & Lysaght, R. J. (1989, October). OWLKNEST: An expert system to provide operator workload guidance. In Proceedings of the Human Factors Society Annual Meeting (Vol. 33, No. 20, pp. 1486-1490). Sage CA: Los Angeles, CA: SAGE Publications.	The Operator Workload Knowledge-based Expert System Tool (OWLKNEST) is a microcomputer-based tool that provides guidance in selecting the most appropriate technique to use for estimating Operator Workload (OWL) for developing Army systems. OWLKNEST is based on twenty years of workload research and on knowledge gained in the three-year Army Research Institute OWL Program. The design approach is presented along with a general description of targeted users and knowledge representation scheme. The criteria used to evaluate available OWL techniques for inclusion in the system are also presented. Sample system applications are presented which illustrate how OWLKNEST can be used for a variety of needs.	
2000	Hassi, J., Gardner, L, Hendricks, S., Bell, J. 2000. Occupational Injuries in the Mining Industry and their Association with Statewide Cold Ambient Temperatures in the USA. American Journal of Industrial Medicine 38:49–58.	Relatively few occupational epidemiological studies have been conducted concerning the association between cold ambient temperatures and cold exposure injuries, and fewer still of traumatic occupational injuries and cold ambient temperatures. The association of ambient temperature and wind data from the National Climatic Data Center with injury data from mines reported to the Mine Safety and Health Administration (MSHA) was evaluated over a 6 year period from 1985-1990; 72,716 injuries from the seven states with the most numerous injuries were included. Temperature and wind data from each state's metropolitan weather stations were averaged for each day of the 6 year period. A weighted linear regression tested the relationship of ungrouped daily temperature and injury rate for all injury classes. For cold exposure injuries and fall injuries, relative incidence rates for grouped temperature data were fit with Poisson regression. As temperatures decreased, injury rates increased for both cold exposure injuries and slip and fall injuries. The association of slip and fall injuries with temperature was inverse but not strictly linear. The strongest association appeared with temperatures 29 degrees F and below. The injury rates for other accident categories increased with increasing ambient temperatures. This study suggests that statewide average ambient temperature reflects the expected association between the thermal environment and cold exposure injuries for workers, but more importantly, documents an association between ambient temperatures and occupational slip and fall injuries.	Demonstrates occupational accident rate is inversely related to cold temp nonlinearly with strongest association at or below 36°F
2011	Heaver, C., Goonetilleke, K. S., Ferguson, H., & Shiralkar, S. (2011). Hand–arm vibration syndrome: a common occupational hazard in industrialized countries. Journal of Hand Surgery (European Volume), 36(5), 354-363.	Regular exposure to hand-transmitted vibration can result in symptoms and signs of peripheral vascular, neurological and other disorders collectively known as the hand-arm vibration syndrome (HAVS). A significant proportion of workers can suffer from HAVS after using vibrating power tools. HAVS is a chronic and progressive disorder. Early recognition and prevention is the key to managing vibrating tool exposures and health effects. This article gives a broad overview of the condition with a detailed account of its pathogenesis, identification and management.	
1993	Hebdon, F.J. 1993. *Effect of Hurricane Andrew on the Turkey Point Nuclear Generating Station from August 20--30, 1992. [Final Report].* "Other Information: PBD: Mar 1993." NUREG--1474;	This is the report of the team that the US Nuclear Regulatory Commission (NRC) and the Institute of Nuclear Power Operations (INPO) jointly sponsored (1) to review the damage that the hurricane caused the nuclear units and the utility`s actions to prepare for the storm and recover from it, and (2) to compile lessons that might benefit other nuclear reactor facilities.	Potential info on environmental stressors associated with severe environmental conditions at nuclear power plants
2014	Heitz, R.P. 2014. The Speed-Accuracy Tradeoff: History, Physiology, Methodology, and Behavior. Frontiers in Neuroscience (8):150, 1-19.	There are few behavioral effects as ubiquitous as the speed-accuracy tradeoff (SAT). From insects to rodents to primates, the tendency for decision speed to co-vary with decision accuracy seems an inescapable property of choice behavior. Recently, the SAT has received renewed interest, as neuroscience approaches begin to uncover its neural underpinnings and computational models are compelled to incorporate it as a necessary benchmark. The present work provides a comprehensive overview of SAT. First, I trace its history as a tractable behavioral phenomenon and the role it has played in shaping mathematical descriptions of the decision process. Second, I present a "users guide" of SAT methodology, including a critical review of common experimental manipulations and analysis techniques and a treatment of the typical behavioral patterns that emerge when SAT is manipulated directly. Finally, I review applications of this methodology in several domains.	
1984	Helmcamp J.C., E.O. Talbott, and G.M. Marsh. 1984. Whole body vibration—A critical review. Am Ind Hyg Assoc J 45: 162-167.	This paper critically reviews the existing literature and summarizes the known health effects of whole body vibration. Experimental study results are generally inconsistent and dependent on the characteristics of the vibration exposure.	Vibration effects on subjective discomfort and chronic health
2012	Helton, W.S., and J. Head. 2012. "Earthquakes on the Mind: Implications of Disasters for Human Performance." *Human Factors* 54(2):189-194.	Discussion about how major disasters affect human performance	Natural disasters and human performance impacts
2015	Hidaka, S. and M. Ide. 2015. Sound can suppress visual perception. Sci. Rep. 5, 10483; doi: 10.1038/srep10483. http://www.nature.com/articles/srep10483.pdf.	Here, we investigated whether sound could have a suppressive effect on visual perception. We found that white noise bursts presented through headphones degraded visual orientation discrimination performance. This auditory suppression effect on visual perception frequently occurred when these inputs were presented in a spatially and temporally consistent manner. These results indicate that the perceptual suppression effect could occur across auditory and visual modalities based on close and direct neural interactions among those sensory inputs.	Cross modal effects of Noise on visual perception
2015	Hidaka, S. Masakazu, I. 2015. Sound can Suppress visual perception.	Direct behavioral evidence regarding the audio-visual perceptual suppression effect was investigated by using sound. White noise bursts presented through headphones degraded visual orientation discrimination performance. Auditory suppression effect on visual perception frequently occurred when inputs were presented in a spatially and temporally consistent manner.	Results indicate that the perceptual suppression effect could occur across auditory and visual modalities based on close and direct neural interactions among those sensory inputs. Noise could degrade in these environments as well.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1996	Hill, J.R., and C.F. Miller. 1996. "Personnel Injuries/Illnesses Associated with Natural Environment Hazards." *Applied Occupational and Environmental Hygiene* 11(4):349-353. http://dx.doi.org/10.1080/1047322X.1996.10389335.	The purpose of this article is to demonstrate how an existing U.S. Department of Energy (DOE) resource can be used to obtain "lessons-learned" information concerning injuries or illnesses resulting from on-the-job hazards. That resource is the Computerized Accident/Incident Reporting System (CAIRS) module of DOE's Safety Performance Measurement System (SPMS).	Potential source for additional hazards/stressors from environmental conditions.
2003	Hobbs, A., and A. Williamson. 2003. "Associations between Errors and Contributing Factors in Aircraft Maintenance." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 45(2):186-201. http://hfs.sagepub.com/content/45/2/186.abstract.	Cognitive error models have provided insights into the unsafe acts that lead to many accidents in safety-critical environments	Possible links between specific errors and contributing factors
1975	Hodge, D.C., and J. Mazurczak. 1975. *Human Performance Criteria for Military Noise Exposure.* Technical Note 2-75, Human Engineering Laboratory, Aberdeen Proving Ground, Maryland.	Discusses quantification of the effects of aural acuity deficits on human performance	Potential framework for quantification of noise stress
1986	Hood DC & Finkelstein MA. (1986). Sensitivity to light. In: Boff KR, Kaufman L, Thomas JP, editors. Handbook of perception and human performance, Vol I: Sensory processes and perception. New York: John Wiley; p. 5-1–5-66.		
2014	Hooper, E., Chapman, L., and Quinn, A. 2014. Investigating the Impact of Precipitation on Vehicle Speeds on UK Motorways. Meteorological Applications 21:194- 201.	The results of this study show that whilst precipitation does impact on traffic speeds, there is no universal significant single factor relationship between the two variables and only a small amount of variance in traffic speeds can be explained by the intensity of precipitation.	Effect of precipitation on traffic speed at group level
2015	Horton, L.M., M.A. Nussbaum, and M.J. Agnew. 2015. "Rotation During Lifting Tasks: Effects of Rotation Frequency and Task Order on Localized Muscle Fatigue and Performance." *J Occup Environ Hyg* 12(2):95-106. http://www.ncbi.nlm.nih.gov/pubmed/25551257.	The purpose of the current study was to quantify the effects of rotation and parameters of rotation (frequency and task order) on muscle fatigue and performance.	Manual actions involving lifting tasks
2006	Hranac, R., Sterzin, E., Krechmer, D., Rakha, H., and Farzaneh, M. 2006. Empirical Studies on Traffic Flow in Inclement Weather. FHWA-HOP-07-073. Washington, DC. Available at www.ops.fhwa.dot.gov/publications/weatherempirical/weatherempirical.pdf.	The results of the research conducted for this study were helpful in identifying weather impacts of traffic flow. No impacts were found on traffic stream jam density, but both rain and snow did impact traffic free-flow speed, speed-at-capacity and capacity and parameters varied with precipitation intensity.	Effect of precipitation on traffic speed at group level
2007	Hughes R.W., F. Vachon, and D.M. Jones. 2007. Disruption of short-term memory by changing and deviant sounds: support for a duplex-mechanism account of auditory distraction. Journal of Experimental Psychology: Learning, Memory, and Cognition 33(6):1050-1061.	The disruption of visual–verbal serial recall by changing-state speech was independent of the effect of a single deviant voice embedded within the speech (Experiment 1); a voice-deviation effect, but not a changing-state effect, was found on a missing-item task (Experiment 2); and a deviant voice repetition within the context of an alternating-voice irrelevant speech sequence disrupted serial recall (Experiment 3). The authors conclude that the changing-state effect is the result of a conflict between 2 seriation processes being applied concurrently to relevant and irrelevant material, whereas the deviation effect reflects a more general attention-capture process.	Cross modal effects of Noise on visual perception
2011	Illuminating Engineering Society. (2011). The lighting handbook: Reference and Application. (10th ed.) (D. L. DiLaura, K. W. Houser, R. G. Mistrick, G. R. Steffy, Eds.). US: IES	The Bible for anyone who is serious about lighting. Covers all technologies, recommended applications and illuminance recommendations and much, much more.	

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
998	Imamura, R., S. Rissanen, M. Kinnunen, and H. Rintamaki. 1998. "Manual Performance in Cold Conditions While Wearing Nbc Clothing." Ergonomics 41(10):1421-1432. http://dx.doi.org/10.1080/001401398186180.	Manual performance while wearing a whole body covering NBC garment was studied at -10 degrees C. Hands were protected by thin cotton gloves, which were covered with rubber gloves. The test subjects were exposed for 40 min in one of the four conditions: standing at -10 degrees C, standing for 10 min followed by walking (5 km/h) for 30 min on a treadmill, standing while holding a solid steel bar (see section 2.2), or standing at 20 degrees C. Six different manual tasks were performed after each 40-min exposure. All tests were also performed with bare hands at 20 degrees C. Moreover, the effect of contact cooling on skin temperatures and rewarming thereafter was examined by means of gripping a steel bar (-10 degrees C) during cold exposure. During exposure to -10 degrees C conditions finger skin temperature rapidly decreased to 10.7 +/- 2.2 degrees C (mean +/- SD). Improvement of body heat balance by exercise increased finger temperatures to 19.6 +/- 9.0 degrees C. Hand temperature remained at a higher level both during rest and exercise at -10 degrees C (20.1 +/- 1.7 and 20.6 +/- 6.1 degrees C, respectively). Cold exposure deteriorated manual performance and especially those functions that are related to finger dexterity. Finger skin temperature had high correlation with screwing, peg-board and magazine loading tests (r = -0.90, r = -0.77 and r = -0.72, respectively, $p < 0.01$) but no relation was found with hand grip strength (r = -0.03). Manual performance was impaired in every test both by gloves and cooling. Contact cooling decreased skin temperatures on the palm side of the hand and fingers around twice as effectively in normothermic subjects and 3.9-6.5 times more effectively in cooled subjects in comparison to cooling by cold air alone. Contact cooling had no significant effect on skin temperatures on the dorsal side of the fingers. The rewarming rate after the release of the steel bar was clearly higher in the dominant hand in comparison to the non-dominant hand. In conclusion, the present results show that the thermal insulation of rubber gloves was clearly insufficient, allowing unacceptably low finger temperatures during work in the cold. However, only those tasks requiring finger dexterity were clearly adversely affected. Heat production by physical exercise was able to increase finger skin temperature and to partly restore manual performance. Handling of cold tools is especially harmful for the palm side temperature of the non-dominant hand.	
2011	IOSH (Institute of Occupational Safety and Health). 2011. Lightning Safety Awareness. Safety Training Presentation available at https://www.osha.gov/dte/grant_materials/fy11/sh-22297-11/LightningSafety.ppt.	IOSH Lightning safety circular, with background and statistics	Lightning effects on health and safety
2016	Jacklitsch B, W.J. Williams, K. Musolin, A. Coca, J-H Kim, and N. Turner. 2016. NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments. DHHS (NIOSH) Publication 2016-106, U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Cincinnati, Ohio	NIOSH review article for Heat and standards	Includes RALs for Heat cited in report
2005	Jiang, Z., G. Shin, J. Freeman, S. Reid, and G.A. Mirka. 2005. "A Study of Lifting Tasks Performed on Laterally Slanted Ground Surfaces." *Ergonomics* 48(7):782-795. http://search.proquest.com/docview/29597529?accountid=26501.	Study discusses outdoor work environments that require manual material handling activities on variable grade ground surfaces. The aim of the current study was to quantify the effect of laterally slanted ground surfaces on the biomechanical response.	Quantifying the biomechanical response while lifting under these conditions
1977	Johnson, D.J., Leider F.E. 1977. Influence of Cold Bath on Maximum Handgrip Strength, Perception and Motor Skills, 1977, 44, 323-326.	Studied 30 min cold bath treatments on the forearm test grip strength. Grip was significantly decreased immediately following the cold bath.	Cold temperature can affect the ability to maintain grip.
2010	Johnson, E.C., M.S. Ganio, E.C. Lee, R.M. Lopez, B.P. McDermott, D.J. Casa, C.M. Maresh, and L.E. Armstrong. 2010. "Perceptual Responses While Wearing an American Football Uniform in the Heat." *Journal of Athletic Training (National Athletic Trainers' Association)* 45(2):107-116. http://search.ebscohost.com/login.aspx?direct=true&db=cin20&AN=2010604445&site=ehost-live.	Purpose is to evaluate perceptual responses of players while wearing different uniforms during exercise in the heat and to evaluate how these responses may be used to monitor athlete safety	Applicability to understanding heat stress applicable to clothing in a hot environment
1986	Johnson, R.F., and L.A. Sleeper. 1986. "Effects of Chemical Protective Handwear and Headgear on Manual Dexterity." in Proceedings of the Human Factors Society, 30th Annual Meeting, pp. 994-997. Dayton, Ohio	Performance related affects associated with wearing protective equipment	Protective clothing related performance degradation
1990	Jones D. 1990. Progress and prospects in the study of performance in noise. In Berglund B., Lindvall T. (Eds.), Proceedings of the Fifth International Congress on Noise as a Public Health Problem. Vol. 3. Stockholm: Swedish Council for Building Research. Pp. 383–400		
2008	Jonkman, S.N., and E. Penning-Rowsell. 2008. "Human Instability in Flood Flows." *JAWRA Journal of the American Water Resources Association* 44(5):1208-1218. http://dx.doi.org/10.1111/j.1752-1688.2008.00217.x.	Loss of human stability in flood flows and consequent drowning are a high personal hazard. In this paper, we review past experimental work on human instability. The results of new experiments by the Flood Hazard Research Centre (FHRC) are also reported.	Model for human instability in flood water

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2005	Jonkman, S.N., and I. Kelman. 2005. "An Analysis of the Causes and Circumstances of Flood Disaster Deaths." *Disasters* 29(1):75-97. http://dx.doi.org/10.1111/j.0361-3666.2005.00275.x.	The objective of this paper is to investigate and to improve understanding of the causes and circumstances of flood disaster deaths. A substantial number of flood disaster fatalities are not related to drowning.	Identify other potential environmental stressors associated with severe weather
2005	Jonkman, S.N., I. Kelman, and V. Bain. 2005. "A Physical Interpretation of Human Stability in Flowing Water." in International Symposium on Stochastic Hydraulics 2005, pp. 90-91. Nijmegen, Netherlands http://www.hydraulicengineering.tudelft.nl/fileadmin/Faculteit/CiTG/Over_de_faculteit/Afdelingen/Afdeling_Waterbouwkunde/sectie_waterbouwkunde/people/personal/gelder/workshops/doc/ISSH.pdf#page=90.	Several authors have proposed limits for human stability in flowing water in the form of a critical depth-velocity (hvc) criterion has received less attention. This paper investigates the physical background of the hvc criterion.	Model for human instability in flood water
2008	Jordan, S., T. Johnson, M. Sterling, and C. Baker. 2008. "Evaluating and Modelling the Response of an Individual to a Sudden Change in Wind Speed." Building and Environment 43(9):1521-1534. http://www.sciencedirect.com/science/article/pii/S0360132307001631.	This paper is concerned with the latter issue and outlines a series of physical and numerical experiments undertaken in order to evaluate the response of an individual to a sudden change in wind speed.	Numerical models of Wind speed effects on gross motor
2003	Just, M.A., Carpenter, P.A., and Miyake, A. 2003. Neuroindices of Cognitive Workload: Neuroimaging, Pupillometric and Event-Related Political Studies of Brain Work. Theoretical Issues in Ergonomics Science 4(1-2):56-88.	This article is a selective theory-driven review that synthesizes recent neuroscience findings concerning mental workload during complex cognition from the perspective of a functional resource theory called 3CAPS, focusing on the concept of capacity utilization. Capacity utilization refers to the proportion of resources that is being consumed in a given time interval in a given cognitive system. This definition integrates the dynamic effects of (a) the computational demand imposed by a task, and (b) the resource supply in an individual that is available to meet that demand. The analysis reveals that the functional relations between capacity utilization and measures of neural activity are similar across three different cognitive systems (language comprehension, visuospatial processing and executive processing). The measures of neural activity include functional neuroimaging, pupillary dilation and event-related potentials. The construct of capacity utilization provides a mapping between a functional architecture of cognition and aspects of its neural implementation.	
2007	Kahya, E. 2007. "The Effects of Job Characteristics and Working Conditions on Job Performance." *International Journal of Industrial Ergonomics* 37515-523. http://theergonomicscenter.com/pdfs/job_satisfaction.pdf	Study reports the effects of job characteristics (physical efforts and job grade), working conditions (environmental conditions and hazards) in addition to experience and education level on task performance	Impact of environmental stressors on performance
2000	Karvonen, R.A., A. Hepojoki, H.K. Huhta, and A. Louhio. 2000. The Use of Physical Models in Dam-Break Analysis. RESCDAM. Final Report. Helsinki University of Technology, Helsinki, Finland.	One part of the RESCDAM project was a research carried out at the Laboratory of water resources at the Helsinki University of Technology. The 3 goals of this project was to test 1) human stability and maneuverability in flowing water, 2) permanence of houses in flowing water and 3) roughness coefficients of forest and houses. Human stability and maneuverability and the permanence of houses in flowing water were studied to produce information for the rescue authorities estimating the risks of a dam break flood and planning the rescue actions. The roughness coefficients of forest and houses were of interest to produce parameters for the mathematical models used to calculate the propagation of dam-break flood. Human stability and roughness coefficient of forest and houses were studied using physical laboratory tests. Experiments on the human stability were conducted testing full scale test persons in the 130 m long model basin equipped with towing carriage in the Helsinki University of Technology Ship Laboratory. The roughness coefficient was studied in the 50 m long fixed bed flume at the Laboratory of Water Resources using scale model forests and houses. The permanence of houses in flowing water was based on literature.	Research was source for one of the sets of the critical human topple data in Figure 6.10-3
1988	Kaufman, J.W., Dejneka, K.Y., Morrissey, S.J., Bagian, J.P. and Bittner, A.C. 1988. Cold Water Evaluation of NASA Launch Entry Suit (LES). Warnminster, PA: Naval Air Development Center (ADA213047). Available at http://www.dtic.mil/get-tr-doc/pdf?AD=ADA213047.	The purpose of this study was to evaluate whether the National Aeronautics & Space Administrations (NASA) Launch Entry Suit (LES) with a personal flotation system and raft could provide sufficient anti-exposure protection for Space Shuttle crews to survive 24 hours of cold water immersion. Two clothing ensembles, the LES and a standard Navy flight ensemble (27/P), which served as the experimental control, were evaluated for the anti-exposure protection they provided with (LES/r and 27/P/r) and without (LES and 27/P) a derivative of the Navy LRU-18/U raft in simulated ocean conditions. Conditions were selected to simulate expected worst case water and air temperatures along projected Space Shuttle ground track, i.e., water temperatures = 4.4 C (40 F), air temperature = 5.6 C (42 F), 1 foot waves (chop), and constant spray. Four males and one female were studied once in each of the configurations. Trials with and without the raft lasted up to 24 and 6 hours, respectively. None of the subjects proved able to endure the test conditions for the planned maximum exposure periods. Mean LES trial durations were 150 + or - 9 minutes and final rectal temperatures (Tre,f) = 36.5 + or - 0.3 C. LES trials were terminated for reaching I(re) = 35.0 0.4 C or subject requested termination due to discomfort. The longest LES run was terminated due to discomfort. Mean LES/r trial durations were 398 + or - 126 minutes and final T(re) = 35.6 + or - 0.4 C. The longest LES/r trial was terminated due to subject discomfort.	One of the studies where isometric or other exercise serve to generate body heat, a tactic not employed by other immersion studies contrasted with non-immersion e.g., Castellani et al. (2001)
2014	Keis, O., H. Helbig, J. Streb, and K. Hille. 2014. Influence of blue-enriched classroom lighting on students' cognitive performance. Trends in Neuroscience and Education 3:86–92.	The effects of classroom lighting on cognitive performance were assessed using standardized psychological tests. Results show beneficial effects of blue-enriched white light on students' performance. In comparison to standard lighting conditions, students showed faster cognitive processing speed and better concentration. The blue-enriched white lighting seems to influence very basic information processing primarily, as no effects on short-term encoding and retrieval of memories were found.	Lighting characteristics that aid cognitive performance and alertness

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2015	Kellnhofer, P., T. Ritschel, K. Myszkowski, E. Eisemann, and H-P. Seidel. 2015. Modeling luminance perception at absolute threshold. In Proceedings of the 26th Eurographics Symposium on Rendering (EGSR '15) 34(4):155-164. Eurographics Association, Aire-la-Ville, Switzerland.	When human luminance perception operates close to its absolute threshold, i. e., the lowest perceivable absolute values, appearance changes substantially compared to common photopic or scotopic vision. In particular, most observers report perceiving temporally-varying noise. Two reasons are physiologically plausible; quantum noise (due to the low absolute number of photons) and spontaneous photochemical reactions. Previously, static noise with a normal distribution and no account for absolute values was combined with blue hue shift and blur to simulate scotopic appearance on a photopic display for movies and interactive applications (e.g., games). We present a computational model to reproduce the specific distribution and dynamics of scotopic noise for specific absolute values. It automatically introduces a perceptually-calibrated amount of noise for a specific luminance level and supports animated imagery. Our simulation runs in milliseconds at HD resolution using graphics hardware and favorably compares to simpler alternatives in a perceptual experiment.	Contemporary analytic-computational model of luminance perception at absolute threshold.
2001	Kemmlert, K., and Lundholm, L. 2001. Slips, Trips and Falls in Different Work Groups--With Reference to Age and from a Preventive Perspective. Applied Ergonomics 32:149-53.	Findings suggest that older male and female workers had higher rates of reported STF accidents than younger workers, but it was established that within any one occupation the workplace hazards were common to all.	Ice/snow related slips and individual differences variables
2004	Kennedy, R. S., Compton, D. E., & Kennedy, R. C. (2004). Effects on human performance of very low frequency vibration (<1 Hz). Paper presented at the Modeling Stress Effects for Performance Prediction Symposium, University of Central Florida, July 7, 2004, Orlando, FL.	There is a growing body of data showing that low frequency noise (LFN), defined as broadband noise with dominant content of low frequencies (10-250 Hz),/ low frequency vibration differs in its nature from other environmental noises and vibrations at comparable levels. The aim of the study was to investigate how LFN at levels normally occurring in the industrial control rooms can influence human performance.	Discusses performance effects of very low frequency vibration (>1Hz but esp. ~0.2Hz) which occasion motion-sickness.
2010	Khan, Z. Rizvi, Z.A. 2010. A Study on the Effects of Human Age, Type of Computer and Noise on Operators' Performance of a Data Entry Task. International Journal of Occupational Safety and Ergonomics 2010, Vol. 16, No. 4, 455–463	Performance (words typed per minute) decreased when noise level increased from 82 to 92 dB (A), but it improved at 102 dB (A). Worker age was also studied and the best group was the 16-25, with the second best 26-40. Also compared laptop vs desktop and discovered desktop had the most words per minute but it was not significant.	Computer operators' data entry task decreased upon noise level increases from 82 to 92, but increased at 102 but not greater than 82.
2012	Khani JR, Saremi M, Kavousi A, Monazam MR & Adedi M (2012 The effect of whole-body vibration on vehicle driver's reaction time and mental and physiological workload. Annals of Military & Health Sciences Research; 10(4): 278-284	In this laboratory and interventional study, 40 volunteers from university students (all male with average age 23.07±2.5 and average BMI 22.8±1.07) randomly selected. Participants were exposed to three levels of whole-body vibration (low, average, high), 3-7 Hertz frequency in vertical direction produced with a vibration simulator. Participants performed a selective visual reaction time test, with correct and incorrect answers and average heart rate (as an indicator of physiological workload) recorded. Following a 5-minute break, participants fill out the NASA TLX questionnaire. The study showed that the vibration intensity has a significant effect on average heart rate (P=0.000), mental workload (P=0.01), average of correct answers (P=0.01) and incorrect answers (P=0.01), But it has no effect on reaction time.	
2011	Kim, J.-H., A. Coca, W.J. Williams, and R.J. Roberge. 2011. "Effects of Liquid Cooling Garments on Recovery and Performance Time in Individuals Performing Strenuous Work Wearing a Firefighter Ensemble." *J Occup Environ Hyg* 8(7):409-416. http://dx.doi.org/10.1080/15459624.2011.584840.	This study investigated the effects of body cooling using liquid cooling garments (LCG) on performance time (PT) and recovery in individuals wearing a fully equipped prototype firefighter ensemble (PFE) incorporating a self-contained breathing apparatus (SCBA)	Potential application for environmental stressor synergy associated with protective clothing
2011	Kim, S., J. Park, and Y.J. Kim. 2011. "Some Insights About the Characteristics of Communications Observed from the Off-Normal Conditions of Nuclear Power Plants." *Human Factors and Ergonomics in Manufacturing & Service Industries* 21(4):361-378. http://dx.doi.org/10.1002/hfm.20270.	Characteristics of communications observed under simulated off-normal conditions of nuclear power plants are investigated.	Communication under abnormal (e.g. flooded) conditions
2010	Kiyatkin, E.A. 2010. "Brain Temperature Homeostasis: Physiological Fluctuations and Pathological Shifts." *Frontiers in Bioscience* 15:73-92	Presents data on fluctuations in brain temperature occurring under physiological and behavioral conditions and discuss their mechanisms. Since most processes governing neural activity are temperature dependent, we consider how naturally occurring temperature fluctuations could affect neural activity and neural functions. Then, we review brain temperature changes induced by psychomotor stimulants and show that the hyperthermic effects of these drugs are state-dependent and modulated by environmental conditions.	Relevant to Heat Mechanism of Action
1990	Kjellberg, A. 1990. Subjective, behavioral and psychophysiological effects of noise. Scandinavian Journal of Work, Environment & Health 16:29-38.	Subjective and psychophysiological responses to noise and the effect of noise on performance is reviewed. Conclusion was that research presents inconsistent picture of these effects.	Review of Noise effects on performance
1975	Klein, D. C., and M. E. P. Seligman. 1975. Reversal of performance deficits and perceptual deficits in learned helplessness and depression. Journal of Abnormal Psychology. 85: 11.	Tested therapeutic implications of the learned helplessness model of depression in 2 experiments with a total of 128 undergraduates. Depression was assessed with the Beck Depression Inventory. Nondepressed Ss receiving inescapable noise and depressed/no-noise Ss later showed noise escape deficits in a shuttlebox and perceptions of response-reinforcement independence when compared with nondepressed/no-noise Ss. Experience with solvable discrimination problems reversed the escape deficits and perceptions of response-reinforcement independence associated with both inescapability and depression. Results support the learned helplessness model of depression, which claims (a) that uncontrollable events induce distorted perceptions of response-reinforcement independence in nondepressed people which cause performance deficits parallel to those found in naturally occurring depression, and (b) that experience with controllable events reverses the perceptions of response-reinforcement independence and the performance deficits associated with both helplessness and depression.	Noise-arousal theory support re: Job related stress effects are more pronounced when noise is louder and/or start and stop out of the worker's control (vs when workers have some control over the noise).

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1971	Knapp, S.C. 1971. *Environmental Effects on Attack Helicopter Crew Task Performance in the Nato Theater.* USAARL Report No. 71-21, U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama.	This report addresses the tasks and demands upon aircraft crew and the effects of the environment on the performance of these tasks.	Impact of environmental stressors on performance
1983	Kobrick, J.L and B.J. Fine. 1983. "Climate and Human Performance." In: D.J. Oborne and M.N. Gruneberg (Eds.), *The Physical Environment at Work.* Chichester: Wiley.		
1988	Kobrick, J.L., and R.F. Johnson. 1988. *Effects of Hot and Cold Environments on Military Performance.* AD-A197 471, U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts.	Discusses thermal stress in military and other industries and impact on human performance	Performance impact from thermal environmental stressors
2004	Koningsvelda, E., Grintena, M.V.D., Molenb, H.V.D., Krausea, F. 2004. A system to test the ground surface conditions of construction sites—for safe and efficient work without physical strain. Applied Ergonomics 36 (2005) 441–448	Discusses terrain and potential risks if not evaluated.	Terrain can lead to many different types of issues including, slips, trips, falls, wrecks, not being sturdy and therefore will give out and cause machines or loads to topple.
2010	Konstantopolous, P., P. Chapman, and D. Crundall. 2010. Driver's visual attention as a function of driving experience and visibility. Using a driving simulator to explore drivers' eye movements in day, night and rain driving. Accident Analysis and Prevention 42:827-834.	Results showed that driving instructors had an increased sampling rate, shorter processing time and broader scanning of the road than learner drivers. This broader scanning of the road could be possibly explained by the mirror inspection pattern which revealed that driving instructors fixated more on the side mirrors than learner drivers. Also it was found that poor visibility conditions, especially rain, decrease the effectiveness of drivers' visual search. The lack of interaction between driving experience and visibility suggests that some aspects of visual search are affected by general rather than situation specific driving experience.	Precipitation effects on driving performance as mediated by experience.
2013	Kornguth, D., D. Steinberg, D. Schnyer, and D. Trujillo. 2013. "Integrating the Human into the Total System: Degradation of Performance under Stress." Naval Engineers Journal 125(4):85-90.	A program funded by the Army Research Laboratory Human Research and Engineering Directorate under the direction of the Center for Strategic and Innovative Technology at the University of Texas at Austin led to findings that total sleep deprivation of 24 to 36 hours had an adverse effect on complex decision making and target identification in experienced soldiers and military cadets. These behavioral changes were correlated with changes in activation of the frontal and parietal regions of the brain as determined by functional magnetic resonance imaging. Diffusion tensor imaging indicated a correlation between the observed fractional anisotropy involving several major fiber pathways of the brain and sustained performance during the period of sleep deprivation. Electroencephalographic properties of the sleep-deprived persons were also correlated with behavioral performance.	total sleep deprivation of 24 to 36 hours had an adverse effect on complex decision making and target identification
2015	Krishnan, H. C., and L.C. Lyons. 2015. Synchrony and desynchrony in circadian clocks: impacts on learning and memory. Learning & Memory 22(9):426-437.	Review article on the effects of light on circadian rhythms which mediate alertness	Relevant to lighting effects on alertness and related cognitive and behavioral performance
1974	Kroemer, K.E. 1974. "Horizontal Push and Pull Forces Exertable When Standing in Working Positions on Various Surfaces." Applied Ergonomics 5(2):94-102.	Physics of standing on various surfaces	Relevant to ice/snow slipping mechanism of action
2008	Kucera, K.L., G.A. Mirka, D. Loomis, S.W. Marshall, H.J. Lipscomb, and J. Daniels. 2008. "Evaluating Ergonomic Stresses in North Carolina Commercial Crab Pot and Gill Net Fishermen." *J Occup Environ Hyg* 5(3):182-196. http://dx.doi.org/10.1080/15459620701873514.	Low back biomechanical stresses associated with crab pot and gill net fishing were estimated to improve understanding of risk factors for low back injury.	Manual lifting tasks and musculoskeletal injury, which impedes human performance
2001	Kyte, M., Khatib, Z., Shannon, P., and Kitchener, F. 2001. Effect of Weather on Free-Flow Speed. In Transportation Research Record 1776, Transportation Research Board, National Research Council, Washington, DC. Pp. 60-68.	Observational study of free-flow driving speed effects of Precipitation	Precipitation primarily reduces speed of vehicles
1998	Lafrance, C., M. Dumont, P. Lespérance, and C. Lambert. 1998. Daytime vigilance after morning bright light exposure in volunteers subjected to sleep restriction. Physiology & Behavior 63(5):803-810.	This study was designed to test the hypothesis that bright light (BL) can have a stimulating effect on vigilance even in the absence of suppression of melatonin secretion and that this effect can be detected when measured in subjects with low vigilance levels. After two nights of sleep restriction, subjective alertness and daytime sleep latencies decreased significantly, but there was no effect of the light treatment. BL treatment did not affect global performance, but there was an effect on the strategy used by the subjects, as shown by faster reaction times and increased percentage of errors in the BL group. It was concluded that daytime BL exposure did not have a stimulating effect on our measures of vigilance even in sleep-deprived subjects but that it may increase physiological arousal and affect the subjects' behavior in some specific performance tasks.	Light effects on alertness and mediated relationships with vigilance performance
2016	Lamb, S., and K.C.S. Kwok. 2016. "A Longitudinal Investigation of Work Environment Stressors on the Performance and Wellbeing of Office Workers." Applied Ergonomics 52104-111. http://www.sciencedirect.com/science/article/pii/S0003687015300375.	This study investigate the effects of inadequate Indoor Environmental Quality (IEQ) on work performance and wellbeing using online surveys measuring perceived thermal comfort, lighting comfort and noise annoyance, measures of work performance, and individual state factors underlying performance and wellbeing. Characterizing inadequate aspects of IEQ as environmental stressors, these stress factors can significantly reduce self-reported work performance and objectively measured cognitive performance by between 2.4% and 5.8% in most situations, and by up to 14.8% in rare cases. Exposure to environmental stress appears to erode individuals' resilience, or ability to cope with additional task demands. Improving IEQ will likely produce small but pervasive increases in productivity.	Environmental stress reduces not only the cognitive capacity for work, but the rate of work (i.e. by reducing motivation). Increasing the number of individual stress factors is associated with a near linear reduction in work performance indicating that environmental stress factors are additive, not multiplicative

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1990	Lamm, R., Choueiri, E.M., and Mailaender, T. 1990. Comparison of Operating Speeds on Dry and Wet Pavements of Two-Lane Rural Highways. In Transportation Research Record 1280, Transportation Research Board, National Research Council, Washington, DC. Pp. 199-207.	Evidence exists to indicate that wet pavement does not have a great effect on operating speed, and that drivers will not adjust their speeds sufficiently to accommodate inadequate wet pavement on curves in particular. Furthermore, results of the statistical analyses indicate that the relationship between operating speed and degree of curve, developed from speed data collected on dry pavements, is also valid for wet pavement conditions so long as visibility is not affected appreciably by heavy rain. It is obvious that the drivers do not recognize the fact that friction supply is significantly lower on wet pavements as compared with dry.	Claims that speed changes do not occur on wet pavement unless precipitation is sufficient to obscure vision
1998	Lance, C.E., Parisi, A.G., Bennett, W.R., Teachout, M.S., Harville, D.L., Welles, M.L. 1998. Moderators of Skill Retention Interval / Performance Decrement Relationships in Eight U.S. Air Force Enlisted Specialties. Human Performance, 11(1),103-123	Extended skill-retention intervals leads to diminished skills performance. Studied degree of initial skill learning, performer aptitude and degree of task difficulty.	Findings indicate more generic skills remained intact and difficult tasks were less intact. Complete more testing to ensure findings are correct.
1996	Lau, W.M. 1996. *Environmental Stressors Affecting Human Physiology and Performance in Northern Australia.* DSTO-TR-0431, DSTO Aeronautical and Maritime Research Laboratory, Melbourne, Australia.	Summarizes findings from visits to several military establishments in high heat and humidity. Areas of research priority were identified and recommendations addressed requirements in physiological performance and survivability in adverse environments.	Performance impact from thermal environmental stressors
2003	Leather, P., D. Beale, and L. Sullivan. 2003. Noise, psychosocial stress and their interaction in the workplace. Journal of Environmental Psychology 23:213–222.	The interaction of noise with psychosocial job stress was explored for office workers employed by a government agency. The results showed no direct effect of ambient noise levels upon job satisfaction, well-being or organizational commitment. However, lower levels of ambient noise were found to buffer the negative impact of psychosocial job stress upon these same three outcomes. Psychosocial job stress is, therefore, seen as a valuable heuristic in operationazing the context of sound events at work.	Low noise can have beneficial impacts on stress in certain circumstances
2002	Lebiere, C., E. Biefeld, R. Archer, S. Archer, L. Allender, and T.D. Kelley. 2002. "Imprint/Act-R: Integration of a Task Network Modeling Architecture with a Cognitive Architecture and Its Application to Human Error Modeling." SIMULATION SERIES 34(3):13-18.	Explores combining ACT-R and IMPRINT models to improve prediction of performance effects	IMPRINT Background
2012	Lee, B.M. 2012. A Field Study of Performance among Embarked Infantry Personnel Exposed to Waterborne Motion. DTIC Document.	With limited information on the aftereffects of waterborne motion on embarked infantry, the Habitability Assessment Test was conducted to investigate and characterize these effects on infantrymen's combat effectiveness. The level of degradation due to exposure to waterborne motion on agility, coordination, and cognitive function was measured utilizing two types of amphibious assault vehicle. Sixty-one Marines were exposed to varying lengths of waterborne motion. They completed a test battery before and after waterborne motion exposure including an obstacle course, marksmanship assessment and cognitive performance test. Analysis reveals no degradation in either marksmanship or obstacle course performance. Cognitive performance, on the other hand, was degraded. Participants' performance on the cognitive test was 9.34 percent lower after exposure to three hours of waterborne motion. Additionally, cognitive performance for participants not reporting to be suffering from motion sickness had a greater deficit. After an one-hour resting period, the participants' performance on the cognitive test was still degraded for the participants exposed to three hours of waterborne motion.	Analysis reveals no degradation in either marksmanship or obstacle course performance. Cognitive performance, on the other hand, was degraded. Participants' performance on the cognitive test was 9.34 percent lower after exposure to three hours of waterborne motion.
1995	Legome, E., A.M.Y. Robins, and D.A. Rund. 1995. "Injuries Associated with Floods: The Need for an International Reporting Scheme." *Disasters* 19(1):50-54. http://dx.doi.org/10.1111/j.1467-7717.1995.tb00332.x.	Discusses morbidity and mortality associated with flooding events.	Potential identification of flooding specific injuries that can degrade performance.
2014	Lehman, B. and A.J. Wilkins, A. J. 2014. Designing to mitigate the effects of flicker in LED Lighting: Reducing risks to health and safety. IEEE Power Electronics Magazine, 1, 18 – 26. http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6891478.	Describes effect of lighting flicker on physiology and performance	Health & safety aspects of Lighting flicker
2011	Leon, G.R., G.M. Sandal, and E. Larsen. 2011. "Human Performance in Polar Environments." *Journal of Environmental Psychology* 31(4):353-360. <Go to ISI>://CCC:000296547100010	An overview of the physical, psychological, social, and coping aspects of living and working in polar regions is presented, assessing findings from both expedition teams and work groups.	Potential source for cold stress performance impact assessment parameters
2006	Lew, R., B.P. Dyre, and B. Wotring. 2006. Effects of Roadway Visibility on Steering Errors while Driving in Blowing Snow. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting 50(16):1656-1660.	The association of ambient temperature and wind data from the National Climatic Data Center with injury data from mines reported to the Mine Safety and Health Administration (MSHA) was evaluated over a 6 year period from 1985-1990; 72,716 injuries from the seven states with the most numerous injuries were included. Temperature and wind data from each state's metropolitan weather stations were averaged for each day of the 6 year period. A weighted linear regression tested the relationship of ungrouped daily temperature and injury rate for all injury classes. For cold exposure injuries and fall injuries, relative incidence rates for grouped temperature data were fit with Poisson regression.	Directional precip. (particularly snow) can induced directional errors leading operators to steer away from the path indicated by visible lane markings
1971	Lewis, R. 1971. *The Effects of Combined Environmental Factors on Human Performance of a Manual Task: Noise and Temperature.* USAMC Intern Training Center - USALMC, Red River Army Depot, Texarkana, Texas.	In this paper, the effects of two environmental factors, noise and temperature, upon human performance of a simple, well-learned manual dexterity task were examined.	Evaluating combined stressors

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2008	Li, C., Z. Bao, and J. Tang. 2008. "Expressway Safety Management System under Adverse Weather." Traffic and Transportation Studies (2008), pp. 988-995. American Society of Civil Engineers, http://dx.doi.org/10.1061/40995(322)93.	In order to mitigate the impacts of adverse weather on transportation mobility, traffic safety, management, and maintenance productivity, the idea of constructing an Expressway Safety Management System (ESMS) that is concerned more with the safety management demand, especially in cases of adverse weather, was put forward in this paper. The author indicated the construction concept, architecture, major functions, and sub-systems of ESMS, which consisted of six sub-systems, namely, traffic and weather monitor sub-system, road weather forecast and impact evaluation sub-system, advanced traffic management sub-system based multi-info resource, intelligent information dissemination sub-system, winter road maintenance decision-support sub-system, and emergency rescue sub-system.	
2006	Li, K.W., Yu, A.R.F., Hanb, X.L. 2006. Physiological and psychophysical responses in handling maximum acceptable weights under different footwear–floor friction conditions. Applied Ergonomics 38 (2007) 259–265	Heart rate, Vo2, energy efficiency, perceived sense of slip, and rating of perceived exertion for whole body strain were measured during a manual movement activity upon three different friction levels. The friction levels adversely affected perception and body mechanics during the activity with the lowest friction being the worst and the highest friction the best.	The implication of this study was that friction level should be regarded as one of the major environmental factors in designing MMH tasks as it affected both physiological and psychophysical responses of the subjects.
2010	Li, Y. and J. Fernie. 2010. Pedestrian Behavior and Safety on a Two-Stage Crossing with a Center Refuge Island and the Effect of Winter on Pedestrian Compliance Rate. Accident Analysis and Prevention 42:1156-1163.	Despite a burgeoning research effort directed at understanding the effects of age, gender, disability, group size, traffic control condition and street width on pedestrian safety and compliance rate as they cross a signalized intersection, remarkably little is known about the compliance rate at a signal controlled two-stage crossing and how pedestrians react to different weather conditions. The purpose of this study was to determine whether pedestrian behavior becomes more risky in inclement weather through the investigation of street crossing behavior and compliance under different weather and road surface conditions at a busy two-stage crossing. Road crossing behavior was filmed at one eight-lane divided road strip at a downtown site in Toronto metropolitan area. The intersection was filmed unobtrusively from a rooftop by one camera set to record both oncoming near-side traffic and pedestrian movements. Pedestrian behavior and compliance rate were scored for a number of determinants of safe road crossing actions. Overall, the results show that road crossing behavior in inclement weather conditions was less safe than in fine weather. The designs of signal timing and configuration of the center refuge island also adversely influenced pedestrian behavior at this crossing, and adverse weather conditions further exacerbated the noncompliance rate. This paper presents new information on compliance rate at a two-stage crossing that emphasizes the need to consider the influence of traffic signal design and weather conditions on pedestrians' behavior. More studies are needed to develop traffic control techniques to allow pedestrians to cross wide two-stage crossings in safety.	pedestrians show increased risk-taking behavior -- during precipitation -- as evidenced by crossing against Don't Walk signals when rain or snow is present
2004	Lind, N., D. Hartford, and H. Assaf. 2004. "Hydrodynamic Models of Human Stability in a Flood." *JAWRA Journal of the American Water Resources Association* 40(1):89-96. http://dx.doi.org/10.1111/j.1752-1688.2004.tb01012.x.	Three approximate mechanical models and two empirical models of the hydrodynamics of toppling are presented and calibrated to align with available experimental observations to assist the analysis of the risk of life loss.	Performance degradation in flood waters
2004	Lipscomb, H.J., D. Loomis, M. Anne McDonald, K. Kucera, S. Marshall, and L. Li. 2004. "Musculoskeletal Symptoms among Commercial Fishers in North Carolina." Applied Ergonomics 35(5):417-426. http://www.sciencedirect.com/science/article/pii/S0003687004000857.	Musculoskeletal symptoms were reported by 215 fishermen followed at 6-month intervals over 18 months. Exposure information was collected through field observation and in-depth ethnographic interviews allowing potential ergonomic stressors to be identified and catalogued by task and stage of work. Symptoms causing work interference in the last 12 months were reported by 38.5% of the cohort at baseline. Low back symptoms were the most common cause of work impairment (17.7%), followed equally by pain in the hands or wrists and shoulders (7%). Symptoms in any body region were more likely to have been reported among individuals who did not fish full-time and those who worked other jobs part or all year had significantly lower symptom prevalence; both likely reflect a healthy worker effect. A number of ergonomic stressors were identified in all stages of fishing with exposure variability dictated by some unpredictable factors such as weather; but also by type of boat, gear, crew size, and level of experience. Reducing ergonomic exposures associated with work among these traditional workers is important, regardless of whether they directly cause or contribute to their musculoskeletal symptoms, or aggravate existing pathology.	
2006	Lipscomb, H.J., J.E. Glazner, J. Bondy, K. Guarini, and D. Lezotte. 2006. "Injuries from Slips and Trips in Construction." Applied Ergonomics 37(3):267-274. http://www.sciencedirect.com/science/article/pii/S0003687005001201.	Summarizes observational data for slips/trips in construction work.	Ice/snow was a significant predictor of slip injuries
2011	Livingston, M.A., C.R. Garrett, and Z. Ai. 2011. Image Processing for Human Understanding in Low-Visibility. DTIC Document.	This study discusses low visibility situations and the researchers' methods to improve visibility by adjusting local contrast of video and digital photos in a varied set of test cases (e.g. snow showers) which would benefit from perceptual enhancement.	Methods for improving visibility in low-visibility situations by processing digital video.
2007	Ljungberg, J. K., & Neely, G. (2007). Cognitive after-effects of vibration and noise exposure and the role of subjective noise sensitivity. Journal of occupational health, 49(2), 111-116.	This study investigated the effects on attention performance after exposure to noise and whole-body vibration in relation to subjective noise sensitivity. Sixteen high and 16 low sensitivity male students, as determined by the Weinstein Noise Sensitivity Questionnaire, participated in a within-subjects experiment. Noise and vibration stimuli similar to those usually occurring in forestry vehicles were presented either individually, combined or not at all in four separate sessions lasting approximately 44 min. After exposure, participants completed an attention task and made subjective ratings of alertness. No main effect of noise sensitivity was observed in MANOVA, thus the data was pooled with the data from a pilot study using the exact same procedure without using a noise sensitivity inclusion criterion. The combined data revealed performance degradation in the attention task after exposure to vibration, regardless as to whether it was presented alone or in combination with noise. Increased ratings of alertness after vibration exposure and decreased ratings of alertness after noise exposure were also found. Neither synergistic nor antagonistic effects were observed from the combined noise and vibration exposure.	
2007	Ljungberg, J., Neely, G. 2007. Stress, subjective experience and cognitive performance during exposure to noise and vibration. Journal of Environmental Psychology 27 (2007) 44–54	Studies whole-body vibration on saliva cortisol levels and subjectively rated difficulty and stress while performing cognitive tasks.	Uses a motion platform to mimic industrial vehicle and tests stress response.

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2004	Ljungberg, J., Neely, G., & Lundström, R. (2004). Cognitive performance and subjective experience during combined exposures to whole-body vibration and noise. International archives of occupational and environmental health, 77(3), 217-221		
2009	Ljungberg, J.K. 2009. "Combined Exposures of Noise and Wholebody Vibration and the Effects on Psychological Responses, a Review." *Noise & Vibration Bulletin* 109-118. http://search.ebscohost.com/login.aspx?direct=true&db=a2h&AN=44276857&site=ehost-live.	Paper discusses psychological responses to combined exposures of noise and whole-body vibration (WBV)	Evaluating combined stressors
2005	Lockhart TL, Jamieson CP, Steinman AM, and Giesbrecht GG. 2005. Life jacket design affects dorsal head and chest exposure, core cooling, and cognition in 10° C water. Aviat Space Environ Med 76: 954–962.	Personal floatation devices (PFDs) differ in whether they maintain the head out of the water or allow the dorsum of the head to be immersed. Partial head submersion may hasten systemic cooling, incapacitation, and death in cold water. Six healthy male volunteers (mean age = 26.8 yr; height = 184 cm; weight = 81 kg; body fat = 20%) were immersed in 10 degrees C water for 65 min, or until core temperature = 34 degrees C, under three conditions: PFD#1 maintained the head and upper chest out of the water; PFD#2 allowed the dorsal head and whole body to be immersed; and an insulated drysuit (control) allowed the dorsal head to be immersed. Mental performance tests included: logic reasoning test; Stroop word-color test; digit symbol coding; backward digit span; and paced auditory serial addition test (PASAT). Core cooling was significantly faster for PFD#2 (2.8 +/- 1.6 degrees C x h (-1)) than for PFD#1 (1.5 +/- 0.7 degrees C x h (-1)) or for the drysuit (0.4 +/- 0.2 degrees C x h (-1)). Although no statistically significant effects on cognitive performance were noted for the individual PFDs and drysuit, when analyzed as a group, four of the tests of cognitive performance (Stroop word-color, digit symbol coding, backward digit span, and PASAT) showed significant correlations between decreasing core temperature to 34 degrees C and diminished cognitive performance. Performance in more complicated mental tasks was adversely affected as core temperature decreased to 34 degrees C. The PFD that kept the head and upper chest out of the water preserved body heat and mental performance better than the PFD that produced horizontal flotation.	
	Lois, E., V.N. Dang, J. Forester, H. Broberg, S. Massaiu, M. Hildbrandt, P.Ø. Braarud, G. Parry, J. Julius, R. Boring, I. Männistö, and A. Bye. 2009. *International HRA Empirical Study – Phase 1 Report, Description of Overall Approach and Pilot Phase Results from Comparing HRA Methods to Simulator Performance Data.* NUREG/IA–0216, Volume 1, Office of Nuclear Regulatory Research, Washington, D.C. ML093380283.	Volume 1 of NUREG/IA-0216 documents the Pilot Phase of the International Human Reliability Analysis (HRA) Empirical Study. This three-phase study is a multinational, multiteam effort supported by the Organization for Economic Cooperation and Development (OECD) Halden Reactor Project, the Swiss Federal Nuclear Safety Inspectorate, the U.S. Electric Power Research Institute, and the U.S. Nuclear Regulatory Commission (NRC). The Pilot has also been documented as a Halden publication: HWR-844, October 2009. The objective of this study is to develop an empirically based understanding of the performance, strengths, and weaknesses of different HRA methods used to model human response to accident sequences in probabilistic risk assessments (PRAs). The empirical basis was developed through experiments performed at the Halden Reactor Project HAMMLAB (HAlden huMan-Machine LABoratory) research simulator, with real crews responding to accident situations similar to those modeled in PRAs. The scope of the study is limited to HRA methods thought appropriate for use in PRAs evaluating internal events during full power operations of current light water reactors. The study consists of performing HRAs for predefined human actions, with different HRA teams using different methods. Nuclear power plant crews perform these human actions at the Halden simulator, Halden experimentalists collect and interpret the data to fit HRA data needs, and an independent group of experts compare the results of each HRA method/team to the Halden crew performance data. The Pilot Phase consisted of developing, testing, and revising the study's methodology and design. Phase 2, which will be documented in Volume 2, consists of the comparison of HRA predictions for all nine steam generator tube rupture human actions. Phase 3, which will be documented in Volume 3, consists of the comparison of four loss-of-feedwater human actions, as well as documentation of the overall study results. The results of the Empirical Study will provide a technical basis for improving individual methods, improving existing guidance documents for performing and reviewing HRAs (e.g., NUREG-1792, HRA Good Practices), and developing additional guidance and training materials for implementing individual methods.	
2014	Lundgren, K., K. Kuklane, and V. Venugopal. 2014. "Occupational Heat Stress and Associated Productivity Loss Estimation Using the Phs Model (Iso 7933): A Case Study from Workplaces in Chennai, India." *Global Health Action* 710.3402/gha.v3407.25283. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4221496/.	Heat stress is a major occupational problem that can cause adverse health effects and reduce work productivity. This paper explores this problem and its impacts in selected workplaces, including industrial, service, and agricultural sectors	Performance impact from thermal environmental stressors
2007	Lupien, S. J., F. Maheu, M. Tu, A. Fiocco, and T.E. Schramek. 2007. The effects of stress and stress hormones on human cognition: Implications for the field of brain and cognition. Brain & Cognition, 65, 209-237.	As temperatures decreased, injury rates increased for both cold exposure injuries and slip and fall injuries. The association of slip and fall injuries with temperature was inverse but not strictly linear. The strongest association appeared with temperatures 29 degrees F and below. The injury rates for other accident categories increased with increasing ambient temperatures.	Integrated review or effects of stress and stress hormones human cognition -- broad implications for all ECs with associated alert- states and/or PORs
1989	Lysaght, R.J., Hill, S.G., Dick, A.O., Plamondon, B.D., Linton, P.M., Wierwille, W.W., Zaklad, A.L., Bittner, A.C., Jr. and Wherry, R.J. (1989). Operator workload (OWL) assessment program for the Army: Comprehensive review and evaluation of operator workload methodologies (ARI Technical Report 851). Alexandria, VA: U.S. Army Research Institute (NTIS AD A212 879).	This report documents the results of an analysis of the scientific literature on Operator workload. It begins with an extensive discussion of the concept and definitions of operator workload. The main body of the report is a review and analysis of techniques that have been used for assessing operator workload. These techniques are classified as to two broad categories: (a) analytical or predictive techniques that may be applied early in system design, and~ (b) empirical or evaluative techniques that must be obtained with an operator-in-the--loop during simulator, prototype, or system evaluations. Information from the review provides practical guidance for selecting the most appropriate techniques for various system and resource characteristics.	

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2005	Mac Duff, L., J.H. De Ridder, and D.D.J. Malan. 2005. "Influences on Human Functional Strength Exertion: Research Article." ergosa Ergonomics SA: Journal of the Ergonomics Society of South Africa 17(1):25-40.	Functional strength is understood as the exertion of muscle strength by an individual in order to carry out functional tasks such as driving a delivery truck that requires the pushing of the gear lever and foot pedals or in the lifting and stacking of boxes. Manual handling of heavy objects requires just such functional strength. It is not an isolated muscle action, but a synergistic action that is the result of both characteristics of the individual and the environment in which they are working. A review of the literature relating to the influences on human functional strength exertion was conducted with the focus on aspects of functional strength for manual handling which could be applied within an ergonomics context. The aim was to understand the challenge in collecting and presenting human strength data which can be best applied by ergonomists and engineers alike to improve the human interface of products, vehicles or machines. The characteristics of the individual such as anthropometric dimensions, aerobic capacity and fitness levels are known to contribute to the ability to exert strength and carry out manual handling tasks which are required in many jobs. The influences such as the environmental stressors, hand coupling and working in restricted spaces have also been discussed. The determination of manual handling capability of an individual or population by a functional test that relates specifically to the ergonomic components of the job remains the most applicable form of data collection.	
1950	Mackworth, N.H. 1950. Researches on the Measurement of Human Performance. London: Her Majesty's Stationery Office. Medical Research Council Special Report Series 268.	In all human performance as it occurs in ordinary life the characteristics of a particular item of behavior appear to depend greatly on its relation to preceding and succeeding items-on its place in a sequence rather than on its character as a separate entity. The investigations here described by Mackworth are all attempts to develop controlled methods for studying and measuring behavior in sequence, and for studying the items of behavior as they occur within the sequence they were undertaken. Visual vigilance was measured mainly by responses to a clock test in which the subject had to press a response key whenever he saw the second hand of a large clock make an unusually large jump forward. For the measurement of auditory vigilance a listening test which reproduced in auditory form some of the features of the clock test was used In the studies of the effects of exposure to high atmospheric temperatures four tests were used, a pull test, a heavy pursuitmeter, a wireless telegraphy reception test, and a coding test In the pull test the subject raised and lowered a 15-pound weight by bending and straightening his arm in time to a metronome. The experiments with vigilance tests showed that for a wide variety of such sensory tasks there is a regular and significant fall of efficiency towards the end of about thirty minutes of work. This was repeatedly confirmed under operational conditions. The result seems to be due to a change in the central nervous or mental control of the whole sequence of the performance. There is no loss of ability to distinguish the signals. The operator can still pick out the signals as readily as at first if they are presented outside the normal sequence, but not if they occur in the setting of the continuous task. The remedy for this fall in efficiency is to arrange shorter spells of duty, or if this is not possible, the fall can be countered by, for instance, giving the operator exact information on the progress he is making. The heat and humidity investigations with a wide variety of long-continued operations showed that there is a definite limit to human tolerance at an effective temperature of 83° to 871/2°F. Below this level considerable and easily distinguishable changes of heat and humidity caused little corresponding change in performance, but above it small changes of environment caused large changes in performance. The direct measurement of the work done was a much better index of change of ability than any known physiological criterion.	
2006	Mäkinen, T. M., Palinkas, L. A., Reeves, D. L., Pääkkönen, T., Rintamäki, H., Leppäluoto, J., et al. (2006). Effect of repeated exposures to cold on cognitive performance in humans. Physiol. Behav. 87, 166–176.	The effects of repeated exposure to cold temperature on cognitive performance were examined in 10 male subjects who were exposed to control (25 degrees C) and cold (10 degrees C) conditions on 10 successive days. A cognitive test battery (ANAM-ICE) was administered each day to assess complex and simple cognitive functioning accuracy, efficiency and response time. Rectal (T (rect)) and skin temperatures, thermal sensations, metabolic rate (M) and cardiovascular reactivity were also recorded. With the used cold exposure, inducing cold sensations and discomfort, superficial skin cooling (6-7 degrees C) and a slightly lowered T(rect) (0.4 degrees C) we observed three distinct patterns of cognitive performance: 1) negative, reflected in increased response times and decreased accuracy and efficiency; 2) positive, reflected in decreased response time and increased efficiency; and 3) mixed, reflected in a pattern of increases in both accuracy and response time and decreases in efficiency, and a pattern of decreases in both accuracy and response time. T(rect), thermal sensations, diastolic blood pressure (DBP) and heart rate (HR) were independent predictors of decreased accuracy, but also decreased response time. Cognitive performance efficiency was significantly improved and response times shorter over the 10-d period both under control and cold exposures suggesting a learning effect. However, the changes in cognitive performance over the 10-d period did not differ markedly between control and cold, indicating that the changes in the thermal responses did not improve performance. The results suggest that cold affects cognitive performance negatively through the mechanisms of distraction and both positively and negatively through the mechanism of arousal.	
2002	Malchaire, J., Geng, Q., Den Hartog, E., Havenith, G., Holmer, I., Piette, A., Powell, S.L., Rintamaki, H. and Rissanen, S. Temperature Limit Values for Gripping Cold Surfaces. Ann. occup. Hyg., Vol. 46, No. 2, pp. 157–163, 2002	Study involved determining temperature limit values for gripping and handling of cold items.	Determined that skin contact temperature not to reach <15C

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2012	Marble, J., H. Liao, M. Presley, J. Forester, A. Bye, V. Dang, and E. Lois. 2012. "Results and Insights Derived from the Intra-Method Comparisons of the Us HRA Empirical Study." in Proceedings of the 11th Probabilistic Safety Assessment and Management/European Safety and Reliability Conference. Helsinki, Finland. [conference paper]	The effects of repeated exposure to cold temperature on cognitive performance were examined in 10 male subjects who were exposed to control (25 degrees C) and cold (10 degrees C) conditions on 10 successive days. A cognitive test battery (ANAM-ICE) was administered each day to assess complex and simple cognitive functioning accuracy, efficiency and response time. Rectal (T(rect)) and skin temperatures, thermal sensations, metabolic rate (M) and cardiovascular reactivity were also recorded. With the used cold exposure, inducing cold sensations and discomfort, superficial skin cooling (6-7 degrees C) and a slightly lowered T(rect) (0.4 degrees C) we observed three distinct patterns of cognitive performance: 1) negative, reflected in increased response times and decreased accuracy and efficiency; 2) positive, reflected in decreased response time and increased efficiency; and 3) mixed, reflected in a pattern of increases in both accuracy and response time and decreases in efficiency, and a pattern of decreases in both accuracy and response time. T(rect), thermal sensations, diastolic blood pressure (DBP) and heart rate (HR) were independent predictors of decreased accuracy, but also decreased response time. Cognitive performance efficiency was significantly improved and response times shorter over the 10-d period both under control and cold exposures suggesting a learning effect. However, the changes in cognitive performance over the 10-d period did not differ markedly between control and cold, indicating that the changes in the thermal responses did not improve performance. The results suggest that cold affects cognitive performance negatively through the mechanisms of distraction and both positively and negatively through the mechanism of arousal.	
2012	Marble, J., H. Liao, M. Presley, J. Forester, A. Bye, V. Dang, and E. Lois. 2012. "Results and Insights Derived from the Intra-Method Comparisons of the Us HRA Empirical Study." in Proceedings of the 11th Probabilistic Safety Assessment and Management/European Safety and Reliability Conference. Helsinki, Finland [slides]	Human reliability analysis (HRA) is an important aspect of PRA which evaluates the contribution of human performance to risk. But HRA is a major contributor to variability in PRA results. Different HRA methods rely on different human performance frameworks and data, and analysts may apply the methods inconsistently. The US Nuclear Regulatory Commission (NRC) first proposed, participated in and supported the International HRA Empirical Study, where HRA predictions of different analysts and methods were compared to crew performance data at the Halden Reactor Project simulator facilities. Only one method in that study was applied by multiple teams; therefore method effects could not be separated from analyst effects. A major objective of the US Empirical Study was to test the consistency of HRA predictions among different analyst teams using the same methods. In this study, at least two different analyst teams applied each method to predict the outcome of the scenarios. We examined the qualitative analyses to identify differences and the extent to which the differences in results were due to analysts versus the methods. This paper discusses the insights for method guidance and the intra-method comparisons. A companion paper discusses the empirical data and overall results.	
1978	Marcus, P., & Belyavin, A. (1978). Thermal sensation during experimental hypothermia. Physiology & behavior, 21(6), 909-914.	Ten subjects were cooled to a deep body temperature (TDB) □35°C by the passage of cold air and water over the skin. Four subjects repeated the Exposure on 3 more occasions. Subjective assessments of thermal comfort were recorded using an automated 10 cm line device. Multiple regression analysis showed that comfort was related to the levels and gradients of TDB and mean skin temperature (Ts−) as well as the presence or absence of shivering. First exposures were characterized by extreme discomfort associated with the initial rapid fall of Ts− at the onset of cooling and an improvement in thermal sensation as Ts− plateaued before TDB started to fall. This response was not seen in subsequent experiments. In these, discomfort occurred initially with falling Ts− and then remained constant, finally increasing further as TDB fell, suggesting habituation to steep gradients of Ts−. Other indications of habituation, leading to less discomfort at given levels of Ts− + TDB during later stages of cooling, were not statistically significant. There was no evidence of physiological acclimatization to cold in those subjects undergoing repeated exposures.	
2014	Maresh, C.M., B. Sökmen, L.E. Armstrong, J.C. Dias, J.L. Pryor, B.C. Creighton, C.X. Muñoz, J.M. Apicella, D.J. Casa, E.C. Lee, J.M. Anderson, and W.J. Kraemer. 2014. "Repetitive Box Lifting Performance Is Impaired in a Hot Environment: Implications for Altered Work-Rest Cycles." *J Occup Environ Hyg* 11(7):460-468. http://dx.doi.org/10.1080/15459624.2013.875185.	This study investigated the effects of environmental temperature on repetitive box lifting (RBL) performance	Thermal stress impact on manual actions involving lifting
2010	Martin, D.S., D.Z.H. Levett, M.P.W. Grocott, and H.E. Montgomery. 2010. "Variation in Human Performance in the Hypoxic Mountain Environment." *Experimental Physiology* 95(3):463-470. <Go to ISI>://CCC:000274409700009	Performance degradation related to altitude. For those who are not native to high altitude, the ability to compete at altitude is likely to be impaired. The magnitude of such impairment in performance, however, differs greatly between individuals	Performance degradation affects associated with higher altitude locations
2000	Martin, P., Perrin, J., Hansen, B., and Quintana, I. 2000. Inclement Weather Signal Timings. MPC 01-120. US Department of Transportation: Washington, DC.	This study examines environmental inputs that should be taken into consideration when setting signal timing in inclement weather conditions.	Ice/snow - tendency for pedestrians to walk faster in inclement weather, which can increase probability of slipping
1978	Mason, J. B. 1978. Light Attenuation in Falling Snow. ASL-TR-0013. Atmospheric Sciences Laboratory, White Sands, NM.	This study suggests that statewide average ambient temperature reflects the expected association between the thermal environment and cold exposure injuries for workers, but more importantly, documents an association between ambient temperatures and occupational slip and fall injuries.	work that relies on distance vision outdoors (e.g., surveying, monitoring outdoor security cameras) may be rendered difficult or inaccurate due to the light attenuation effects of precipitation
1979	Masterton, J & Richardson, F. A. 1979. Humidex, a method of quantifying human discomfort due to excessive heat and humidity. Environment Canada, Downsview Ontario, 45 pp.		

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1998	May, A.D. 1998. Capacity and Level of Service for Freeway Systems. Third Interim Report, Phase C, Tasks C1 to C10. National Cooperative Highway Research Program, Washington, D.C.	Determination of the capacities of transportation systems and facilities is a major issue in the analysis of transportation flow. The capacity of a transportation system or facility is defined as the maximum number of vehicles, passengers, or the like, per unit time, which can be accommodated under given conditions with a reasonable expectation of occurrence. Capacity is independent of demand in the sense that it does not depend on the total number of vehicles (or whatever) demanding service. It is expressed in terms of units of some specific thing, however, so that it does depend on traffic composition (for instance, for highways, the percentage of trucks or other heavy vehicles; or for airport runways, the percentage of heavy jet aircraft). It is dependent on physical and environmental conditions, such as the geometric design of facilities or the weather. Finally, capacity is a probabilistic measure. There is some variation from time to time and place to place in the maximum number of units of transportation demand that can be accommodated by similar facilities. Not all of these variations can be accounted for by the normal determinants of capacity. The number quoted as the capacity of a facility represents a value with a reasonable expectation of occurrence, but may be exceeded on occasion. Moreover, it is to be expected that there will be random variations in the number of vehicles that can be accommodated over very short time intervals, so that capacity is often best thought of as the maximum average flow rate that can be sustained indefinitely, so long as there is no lack of demand.	
1971	May, D. N., and C.G. Rice. 1971. Effects of startle due to a pistol shot on control precision performance. Journal of Sound and Vibration, 15: 197-202.	The effect on control precision performance of startle due to 16 pistol shots of 124 dB peak level was investigated in the laboratory using 14 subjects aged 20–29. It was found that performance was significantly impaired in the two seconds following each bang and not thereafter, but that a lessening of this reaction occurred and was reported by the subjects over the length of the experiment. Some evidence was found for the existence of a critical interval between presentations which was thought to mark the longest period for which subjects in a given situation maintain their expectancy. Evidence was also found that performance when startled is not proportional to a subject's learning skill as it is when startle is not present.	
2014	Mazloumi, A., F. Golbabaei, S. Mahmood Khani, Z. Kazemi, M. Hosseini, M. Abbasinia, and S. Farhang Dehghan. 2014. "Evaluating Effects of Heat Stress on Cognitive Function among Workers in a Hot Industry." *Health Promotion Perspectives* 4(2):240-246. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4300451/.	The aim of this study was to evaluate the impact of thermal stress on cognitive function among workers in a hot industry.	Cognitive performance effects related to thermal stress
2005	McCallum, M., Bittner, A., Rubinstein, J., Richman, J., Brown, J., & Taylor, R. (2005). Factors contributing to airport screener expertise. Proceedings of the 49th Annual Meeting of the Human Factors and Ergonomics Society, pp 922-926 [CD-ROM]. Santa Monica, CA: HFES.	An airport X-ray Screener Test Battery was developed to better understand how selected aspects of screeners' visual and perceptual capabilities, attentional and verbal processing, work schedule, medication use, work history, training, equipment knowledge, personal style, attitudinal characteristics, and job satisfaction are related to job performance. The Test Battery was administered to 92 X-ray screeners and analyses compared Test Battery performance with X-ray screening job performance. Analyses suggest that important factors related to X-ray screening performance include several aspects of perceptual and attentional processing; screeners' time on the job; screeners' work schedules; and their use of pharmaceuticals, over-the-counter drugs, and dietary supplements. Potential applications of the findings for improving screener performance through personnel selection, training, workforce management, and X-ray equipment design enhancements are discussed. Ongoing research is also outlined.	
2001	McColl, S.L., and Veitch, J.A. 2001. Full-spectrum fluorescent lighting: a review of its effects on physiology and health. Psychological Medicine 31(6):949-964.	Full-spectrum fluorescent lighting (FSFL) has been credited with causing dramatic beneficial effects on a wide variety of behaviors, mental health outcomes, and physical health effects, as compared to other fluorescent lamp types. These effects are hypothesized to occur because of similarity between FSFL emissions and daylight, which is said to have evolutionary superiority over other light sources. This review, covering the period 1941-1999, critically considers the evidence for direct effects of FSFL through skin absorption as well as indirect effects on hormonal and neural processes. Overall, the evidence does not show dramatic effects of fluorescent lamp type on behavior or health, nor does it support the evolutionary hypothesis.	This mechanism – light enhanced reduction in melatonin and subsequent increase in alertness -- may be partly responsible for the observed improvements in worker performance demonstrated with full-spectrum office lighting systems
1970	McGrath, J.E. (1970). A conceptual formulation for research on stress. In J.E. McGrath (Ed.), Social and psychological factors in stress (pp. 10–21). New York: Rinehart & Winston. 145	This article is part of a set of studies on social and psychological factors in human stress. It considers six major substantive propositions and three key sets of methodological issues and is part of a set of six empirical and theoretical studies of which this is a part. As part of this effort team conducted a field test of a model of stress, reformulated the model based on results of the field study, and conducted several further studies to test the reformulated model.	
1976	McGrath, J.E. (1976). Stress and behavior in organizations. In M.D. Dunnette (Ed.), Handbook of industrial and organizational psychology (pp. 1351–1395). Chicago: Rand McNally.		
1990	McLeod, R.W., and M.J. Griffin. 1990. Effects of whole-body vibration waveform and display collimation on the performance of a complex manual control task. Aviat Space Environ Medicine 61(3):211-219.	The results show that continuous control performance was disrupted by visual interference at frequencies above 1.6 Hz; closed-loop system transfer functions showed that visual interference increased the phase lags which impaired control performance. Possible mechanisms explaining the disruption in performance at lower frequencies are discussed.	Collimation can be used as a mitigation measure

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1962	McQuigg, J. D., and W. L. Decker. 1962. The Probability of Completing Outdoor Work. Journal of Applied Meteorology, 1, 1178-183.	If an outdoor job were being planned in an area which never received precipitation, all facilities could be scheduled with assurance that work could proceed to completion without interruption because of precipitation. In practice, many an outdoor job has been scheduled, only to be delayed several times before actual completion. It would be useful to be able to estimate the probability of completing a job as scheduled. A mathematical model is developed which includes: (1) A scheduled beginning date, (2) An amount of precipitation in one day that would interrupt a job, (3) The number of days of "drying out" time required, (4) The number of work days required. For a particular place and job, the problem is to estimate the probability that a run of dry days will occur during a particular period of time. This could be estimated by counting runs in a sample period, or computed by several methods. In this study probabilities were computed by an approximation technique which yielded estimates comparable to those from counts of actual runs. Probability estimates for different beginning dates and lengths of drying and work periods are presented.	Illustrative attempt to quantify the effects of precipitation on work completion time to produce better planning estimates for outdoor tasks.
2014	Mehta, R.K., and M.J. Agnew. 2014. "Subjective Evaluation of Physical and Mental Workload Interactions across Different Muscle Groups." *J Occup Environ Hyg* 12(1):62-68. http://dx.doi.org/10.1080/15459624.2014.942455.	The aim of this study was to determine the sensitivity of the NASA Task Load Index (NASA TLX) and Ratings of Perceived Exertion (RPE) to evaluate physical and mental workload during muscle-specific tasks.	Measure of cognitive performance impact due to mental stressors. Also potential framework for quantifying performance degradation.
1978	Melbourne, W.H. 1978. "Criteria for Environmental Wind Conditions." Journal of Industrial Aerodynamics 3:241-249.	Since 1971 a number of authors have published criteria for the acceptability of environmental wind conditions for human comfort for a range of activities. This paper notes that it is the forces caused by peak gust wind speeds and associated gradients which people feel most and discusses the relation between peak gust and mean wind speeds. Melbourne's criteria, which have been stated in terms of maximum gust speeds per annum, are shown to define a range of wind-speed probabilities, in particular, the frequency of occurrence of mean wind speeds, which then facilitates comparison between the various published criteria. It is shown that, in spite of the apparent numerical differences in published wind speed criteria and the various subjective assumptions used in their development, there is remarkably good agreement when they are compared on a proper probabilistic basis.	
1983	Merrild, U. and Bak, S. 1983. An Excess of Pedestrian Injuries in Icy Conditions: A High-risk Fracture Group – Elderly Women. Accident Analysis and Prevention 15:41-48.	An "icy condition epidemic" has been analyzed in an investigation of patients treated in a hospital casualty department: it was found that the victims were mainly comprised of pedestrians and that the pedestrians had 14 times more injuries than during a normal winter period.	Identifies individual difference variables associated with slippage in icy conditions
2006	Miller, D.P. and C.R. Lawton. 2006. Human Performance Modeling for System of Systems Analytics: Combat Performance-Shaping Factors. Sandia National Laboratories SAND2006-1111 DOE.	US military Id Human Performance Modeling (HPM) a significant requirement and challenge of future systems modeling and analysis initiatives. Program of HPM as an integral augmentation to its system-of-system analytics capabilities. Survey of performance shaping factors (PSFs) that affect soldiers in combat. Considered 3 approaches to cognition modeling and how appropriate to SoS analytics. Report categorizes 47 PSFs into 3 groups (internal, external, and task-related) and provides descriptions of how each affects combat performance, according to the lit. PSFs were assembled into a matrix of 22 representative military tasks and assigned 1 of 4 levels of estimated negative impact on task performance, based on the lit. Blank versions of the matrix were then sent to 2 ex-military SMEs to be filled out based on their experiences.	Combat-related injury, cognitive fatigue, inadequate training, physical fatigue, thirst, stress, poor perceptual processing, and presence of chemical agents are PSFs with the most negative impact on combat performance.
1933	Missenard FA (1933) Température effective d'une atmosphere Généralisation température résultante d'un milieu. In: Encyclopédie Industrielle et Commerciale, Etude physiologique et technique de la ventilation. Librerie de l'Enseignement Technique, Paris, pp 131–185		
2002	Mohamed, S. and K. Srinavin. 2002. "Thermal Environment Effects on Construction Workers' Productivity." *Work Study* 51:297-302	This paper reports on a research study that focused on predicting the loss of construction workers' productivity due to thermal environment variations. A set of equations reflecting the nature of the construction task being performed as well as the thermal environment are proposed to predict the degree of change in workers' productivity, according to a change in the thermal environment. Validation results indicate that the developed equations can predict productivity with a reasonable level of accuracy. Furthermore, they show that the workers' productivity decreases as the PMV index moves away from the optimum range for all the observed tasks.	Heat effects on productivity for construction workers, predictive models included
1994	Moseley, P.L. 1994. Mechanisms of heat adaptation: thermotolerance and acclimatization. J Lab Clin Med 123(1):48–52.		The human body can ameliorate the physiological effects of heat exposure by acclimation. Within certain limits, 7 to 14 days of consistent but controlled exposure to heat prompts the body to adapt so that homeostatic mechanisms are better able to maintain homeostasis (see also Armstrong and Stoppani 2002).
2012	Muller, M.D., J. Gunstad, M.L. Alosco, L.A. Miller, J. Updegraff, M.B. Spitznagel, and E. Glickman. 2012. "Acute Cold Exposure and Cognitive Function: Evidence for Sustained Impairment." *Ergonomics* 55(7):792–798	Study examining the time-based effects of cold exposure on cognition.	Cold exposure effects on cognition last up to 60 minutes after exposure ends

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1981	Murakami, S. and K. Deguchi. 1981. New criteria for wind effects on pedestrians. J. Wind Eng. Ind. Aerodyn. 7: 289–309. doi:10.1016/0167-6105(81)90055-6.	Experiments concerned with wind effects on pedestrians are described. The experiments consist of three parts. In Part I, walking tests were conducted in a large wind tunnel. In Part II, walking tests were held in a precinct at the base of a high-rke building. Part III again consisted of observation of pedestrians in a precinct at the base of a high-rise building. Recommended quantitative effects limits are proposed.	Quantitative effects of Wind on gross motor
2015	Muthumani, A., L. Fay, and D. Bergner. 2015. Use of Equipment Lighting During Snowplow Operations [Technical Report]. DOI: 10.13140/RG.2.1.3283.3044.	The goal of this research project was to develop a summary of best practices in the use of headlights, work lights, and warning light technology in snowplow operations.	Outlines approaches to mitigating the glare effects of falling snow involve changing the type and positioning of headlights (narrow rather than wide beams; directed away from rather in the operator's line of sight)
1993	Myers, D.C., Gebhardt, D.L., Crump, C.E., Fleishman, E.A. The Dimensions of Human Physical Performance: Factor Analyses of Strength, Stamina, Flexibility, and Body Composition Measures. Human Performance, 6(4), 309-344.	Exercise physiology and factor analysis of individual differences in physical task performances, confirmatory and principal axis factor analyses were carried out on tests selected or designed to cover a wide range of physical abilities.	Gender stats must be separated for strength characteristics. Not much else in this article.
2006	Nakishima, A., & Cheung, B. (2006). The effects of vibration frequencies on physical, perceptual and cognitive performance. (TR 2006-218). Toronto, DRDC. Available at http://www.dtic.mil/docs/citations/ADA472990	In the study of crewmember performance in land-driven vehicles, it is necessary to consider the effects of vibration on the human body. The Advanced Vehicle Architecture for a Net enabled Combat Environment Technology Demonstrator Project (ADVANCE TDP) aims to demonstrate improved crew performance using an integrated multi-layered vectronics network, supported by an active suspension system that stabilizes the vehicle platform. This review discusses the effects of different frequencies and magnitudes of vibration on specific aspects of performance: manual control, vision, perception and cognition. The results of the numerous studies that have been done on manual tracking and visual acuity during vibration exposure have been well-documented and summarized. It has been demonstrated that vibration does not significantly affect performance on simple perceptual tasks involving auditory or visual detection of signals. Vibration has been shown to have a negative effect on complex cognitive tasks; however, vibration frequency or magnitude dependencies have not been proven.	ISO guidance has historically viewed frequency ranges between 0.5 and 80 Hz as being important to human health
2013	Nassiri, P., M. Monazam, B. Fouladi Dehaghi, L. Ibrahim Ghavam Abadi, S.A. Zakerian, and K. Azam. 2013. The Effect of Noise on Human Performance - A Clinical Trial. Int J Occup Environ Med 2013(4):87-95.	1) Steadiness, 2) Minnesota manual dexterity, 3) hand tool dexterity, 4) two-arm coordination. Duration of tests was measured as speed response; to determine error response, time taken committing an error performing a task was measured. Speed response from 4 tests in combined conditions of noise schedule, harmonic index, and SPL was highest for (intermittent, treble, 95 dB), (continuous, treble, 95 dB), (continuous, treble, 85 dB) and (intermittent, treble, 95 dB) respectively. Treble noise was significant in reducing performance; intermittent noise (at high pressure levels) made environmental conditions worse a task.	Manual activities when exposed to different types/levels of noise.
2014	National Research Council. 2014. *Lessons Learned from the Fukushima Nuclear Accident for Improving Safety of U.S. Nuclear Plants.* The National Academies Press, Washington, DC. http://www.nap.edu/catalog/18294/lessons-learned-from-the-fukushima-nuclear-accident-for-improving-safety-of-us-nuclear-plants.	This report examines the causes of the crisis, the performance of safety systems at the plant, and the responses of its operators following the earthquake and tsunami. The report then considers the lessons that can be learned and their implications	Potential info on environmental stressors associated with severe environmental conditions at nuclear power plants
1999	Nayar, S.K., and S.G. Narasimhan. 1999. Vision in Bad Weather. Proceedings of the International Conference on Computer Vision 2:820.	Current vision systems are designed to perform in clear weather. Needless to say, in any outdoor application, there is no escape from "bad" weather. Ultimately, computer vision systems must include mechanisms that enable them to function (even if somewhat less reliably) in the presence of haze, fog, rain, hail and snow. We begin by studying the visual manifestations of different weather conditions. For this, we draw on what is already known about atmospheric optics. Next, we identify effects caused by bad weather that can be turned to our advantage. Since the atmosphere modulates the information carried from a scene point to the observer, it can be viewed as a mechanism of visual information coding. Based on this observation, we develop models and methods for recovering pertinent scene properties, such as three-dimensional structure, from images taken under poor weather conditions.	Precipitation increases the potential for accidents by reducing visibility through either attenuation or reflection of light, in addition to visibility reductions created by direct moisture on eyewear, windows, and windshields. In this regard, rain and snow can be thought of as random spatial variations in scene complexity
2005	Nelson, C. M., & Brereton, P. F. (2005). The European Vibration Directive. Industrial Health, 43, 472-479.	The Directive 2002/44/EC of the European Parliament and of the Council seeks to introduce minimum protection requirements for workers exposed to vibration. It also specifies employers' obligations with regard to determining and assessing risks, and sets out the measures to be taken to reduce or avoid exposure. Furthermore, the directive details how to provide information and training to workers.	
2007	Németh, B., A. Gulyás, I. Kiss, I. Berta. 2007. Practical Use of Preventive Lightning Protection. Conference paper presented at the International Symposium on High Voltage Engineering, Ljubljana, Slovenia. Accessed November 4, 2016 at https://www.researchgate.net/publication/273574339.	Review article on lightning mitigations	Mitigations for Lightning effects on health & safety

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2013	Nenonen, N. 2013. "Analyzing Factors Related to Slipping, Stumbling, and Falling Accidents at Work: Application of Data Mining Methods to Finnish Occupational Accidents and Diseases Statistics Database." Applied Ergonomics 44(2):215-224. http://www.sciencedirect.com/science/article/pii/S0003687012001081.	This study applies methods of data mining (decision tree and association rules) to the Finnish national occupational accidents and diseases statistics database to analyze factors related to slipping, stumbling, and falling (SSF) accidents at work from 2006 to 2007. SSF accidents are more likely to result in longer periods of incapacity for work than other workplace accidents. The most important factor influencing whether or not an accident at work is related to SSF is the specific physical activity of movement. In addition, the risk of SSF accidents at work seems to depend on the occupation and the age of the worker. The results were in line with previous research.	Discusses factors influencing slip, trip, and falls. In addition to low friction surfaces, and movement, increasing age of worker is correlated to increase in slip, trip, falls
2008	Nguyen, L., J. Kneppers, B. García de Soto, and W. Ibbs. 2008. "Analysis of Adverse Weather for Excusable Delays." Journal of Construction Engineering and Management 136(12):1258-1267.	This paper classifies seven factors causing discrepancies in analysis of adverse weather for time extensions; namely, the definition of normal weather, weather thresholds, type of work, lingering days, criteria for lost days, lost days equivalent due to lost productivity, and work days lost versus calendar days lost.	Ways of measuring effect of Precipitation and other adverse weather on productivity
2011	Nickerson, R.S. 2011. "Roles of Human Factors and Ergonomics in Meeting the Challenge of Terrorism." *American Psychologist* 66(6):555-566.	Paper reviews a number of studies and relates terrorism to natural disaster in context of person-system interface design, accident prevention, risk assessment, human performance under various types of stress, crisis management, search and rescue operations, etc.	Potential info on environmental stressors associated with severe environmental conditions at NPPs
1998	NIOSH (National Institute for Occupational Safety and Health). 1998. Criteria for a recommended standard: Occupational noise exposure. U.S. Department of Health and Human Services, Centers for Disease Control and Prevention.	This criteria document reevaluates and reaffirms the recommended exposure limit (REL) for occupational noise exposure established by the National Institute for Occupational Safety and Health (NIOSH) in 1972. The REL is 85 decibels, A-weighted, as an 8-hr time weighted average (85 dBA as an 8-hr TWA). Exposures at or above this level are hazardous. By incorporating the 4000-Hz audiometric frequency into the definition of hearing impairment in the risk assessment, NIOSH has found an 8% excess risk of developing occupational noise induced hearing loss (NIHL) during a 40-year lifetime exposure at the 85-dBA REL. NIOSH has also found that scientific evidence supports the use of a 3-dB exchange rate for the calculation of TWA exposures to noise. The recommendations in this document go beyond attempts to conserve hearing by focusing on prevention of occupational NIHL. For workers whose noise exposures equal or exceed 85 dBA, NIOSH recommends a hearing loss prevention program (HLPP) that includes exposure assessment, engineering and administrative controls, proper use of hearing protectors, audiometric evaluation, education and motivation, recordkeeping, and program audits and evaluations. Audiometric evaluation is an important component of an HLPP. To provide early identification of workers with increasing hearing loss, NIOSH has revised the criterion for significant threshold shift to an increase of 15 dB in the hearing threshold level (HTL) at 500, 1000, 2000, 3000, 4000, or 6000 Hz in either ear, as determined by two consecutive tests. To permit timely intervention and prevent further hearing losses in workers who's HTLs have increased because of occupational noise exposure, NIOSH no longer recommends age correction on individual audiograms.	Classical occupational noise standard for industrial workers
2010	NIOSH (National Institute for Occupational Safety and Health). 2010. Slip, Trip, and Fall Prevention for Healthcare Workers. Centers for Disease Control and Prevention, Washington, DC. Available at: http://www.cdc.gov/niosh/docs/2011-123/pdfs/2011-123.pdf.	NIOSH info sheet for Slip/Trip/Fall prevention for healthcare workers	NIOSH info sheet for Slip/Trip/Fall prevention/mitigation
2009	NOAA. 2009. National Weather Service Glossary. USDC National Oceanic and Atmospheric Administration (NOAA), Silver Spring, MD. (available online only, at http://w1.weather.gov/glossary/ accessed 10 June 2016)	Glossary of weather-related terms.	Obtained definitions of dew point and frost point
2016	NOAA-NASA (National Oceanographic and Atmospheric Administration-National Aeronautics and Space Administration). 2016. What Causes Lightning and Thunder? Accessed November 4, 2016 from http://scijinks.jpl.nasa.gov/lightning/	NOAA fact sheet about Lightning	Attributes/units and causal factors for Lightning
2014	Noroozi, A., R. Abbassi, S. MacKinnon, F. Khan, and N. Khakzad. 2014. "Effects of Cold Environments on Human Reliability Assessment in Offshore Oil and Gas Facilities." *Human Factors* 56(5):825-839. <Go to ISI>://CCC:000340724100003	This paper proposes a new methodology that focuses on the effects of cold and harsh environments on the reliability of human performance.	Performance impacts from thermal stress

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1985	Noweir, M. H. 1985. Noise exposure as related to productivity, disciplinary actions, absenteeism, and accidents among textile workers. Journal of Safety Research, 15(4), 163-174.	A sample of 2458 workers exposed to average noise levels ranging from 80 to 99 dBA in different operations of three textile mills was studied with respect to their productivity, work rule violations, absenteeism, and accidents. The three mills were in rural, suburban, and urban locations. Noise exposure levels were measured in individual departments of the mills, and workers were interviewed to ascertain socioeconomic background, work history data, and health status. Workers' job attitude was rated by their supervisors, and data about their productivity, disciplinary reports, absenteeism, and accidents were collected from plant records. Results of the study suggested that workers in departments with high noise levels (above 90 dBA) had more disciplinary actions and absenteeism and lesser productivity than those in departments with low noise exposure (below 90 dBA). Disciplinary actions showed the greatest difference between the high-noise and low-noise departments followed by production incentives, production efficiency, and absenteeism. Noise appeared to affect the quality of work as reflected by disciplinary actions for material damage, and this effect was higher in weaving and spinning operations which involved vigilance tasks. The frequency and severity rates of accidents in high- noise departments were greater than in low-noise departments. Certain personal and socioeconomic factors affected high vs. low noise exposure differences found among workers for the investigated variables. These effects were most apparent for absenteeism and, to a lesser extent, productivity. Disciplinary actions did not appear to be influenced by any such individual factors. It was concluded that noise abatement in the textile industry could be beneficial to worker productivity and well-being and contribute to more economically effective operation.	
2000	NRC (U.S. Nuclear Regulatory Commission). 2000. *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (Atheana), Appendix A: Representations of Selected Operational Events from an Atheana Perspective.* NUREG–1624, Revision 1, Appendix A, Washington, D.C. ML003719239.	This appendix illustrates the use of the ATHEANA process to investigate the potential for operator actions that ...... document for A Technique for Human Event Analysis (ATHEANA).	
2000	NRC (U.S. Nuclear Regulatory Commission). 2000. *Technical Basis and Implementation Guidelines for a Technique for Human Event Analysis (Atheana).* NUREG–1624, Revision 1, Washington, D.C. ML003719212.	This report describes the most recent version of a second-generation human reliability analysis (HRA) method called "A Technique for Human Event Analysis," (ATHEANA), NUREG-1624, Rev. 1. ATHEANA is the result of development efforts sponsored by the Probabilistic Risk Analysis Branch in the U.S. Nuclear Regulatory Commission's (NRC)'s Office of Nuclear Regulatory Research. ATHEANA was developed to address limitations identified in current HRA approaches by providing a structured search process for human failure events and unsafe acts, providing detailed search processes for error-forcing context, addressing errors of commission and dependencies, more realistically representing the human- system interactions that have played important roles in accident response, and integrating advances in psychology with engineering, human factors, and PRA disciplines. The report is divided into two parts. Part I introduces the concepts upon which ATHEANA is built and describes the motivation for following this approach. Part 2 provides the practical guidance for carrying out the method. Appendix A provides retrospective ATHEANA-based analyses of significant operating events. Appendices B-E provide sample ATHEANA prospective analyses (HRAs) for four specific human performance issues.	
2005	NRC (U.S. Nuclear Regulatory Commission). 2005. *Good Practices for Implementing Human Reliability Analysis (HRA).* NUREG–1792, Washington, D.C. ML051160213.	The U.S. Nuclear Regulatory Commission is establishing "good practices" for performing human reliability analyses (HRAs) and reviewing HRAs to assess the quality of those analyses. The good practices were developed as part of the NRC's activities to address quality issues related to probabilistic risk assessment (PRA) and, as such, support the implementation of Regulatory Guide (RG) 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities," dated February 2004. The HRA good practices documented in this report are of a generic nature; that is, they are not tied to any specific methods or tools that could be employed to perform an HRA. As such, the good practices support the implementation of RG 1.200 for Level 1 and limited Level 2 internal event PRAs with the reactor at full power. Their elements are directly linked to RG 1.200, which reflects and endorses (with certain clarifications and substitutions) the "Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications" (RA-S-2002 and Addenda RA-Sa-2003) promulgated by the American Society of Mechanical Engineers, and "Probabilistic Risk Assessment (PRA) Peer Review Process Guidance" (NEI 00-02, Revision A3) promulgated by the Nuclear Energy Institute. This report is not intended to constitute a standard and, hence, it does not provide de facto requirements; rather, this report is intended for use as a reference guide. Consequently, the authors did not write this report with the expectation that all good practices should always be met. That is, the decisions regarding which good practices are applicable — and the extent to which those practices should be met — depends on the nature of the given regulatory application. Therefore, it is important to understand that certain practices may not be applicable for a given analysis, or their applicability may be of limited scope.	
2007	NRC (U.S. Nuclear Regulatory Commission). 2007. *Demonstrating the Feasibility and Reliability of Operator Manual Actions in Response to Fire.* NUREG–1852, Washington, D.C. ML073020676.	This report provides criteria and associated technical bases for evaluating the feasibility and reliability of postfire operator manual actions implemented in nuclear power plants. The U.S. Nuclear Regulatory Commission (NRC) developed this report as a reference guide for agency staff who evaluate the acceptability of manual actions, submitted by licensees as exemption requests from the requirements of Paragraph III.G.2 of Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating Prior to January 1, 1979," to Title10, Part 50, "Domestic Licensing of Production and Utilization Facilities," of the Code of Federal Regulations (10 CFR Part 50), as a means of achieving and maintaining hot shutdown conditions during and after fire events. The staff may use this information in the review of future postfire operator manual actions to determine if the feasibility and reliability of the operator manual action were adequately evaluated.	

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2012	NRC (U.S. Nuclear Regulatory Commission). 2012. *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines.* NUREG–1921, Washington, D.C. ML12216A104.	During the 1990s, the Electric Power Research Institute (EPRI) developed methods for fire risk analysis to support its utility members in the preparation of responses to Generic Letter 88-20, Supplement 4, and Individual Plant Examination of External Events (IPEEE). This effort produced a fire risk assessment methodology for operations at power plants that was used by the majority of U.S. nuclear power plants (NPPs) in support of the IPEEE program and by several NPPs overseas. Although these methods were acceptable for accomplishing the objectives of the IPEEE, EPRI and the U.S. Nuclear Regulatory Commission (NRC) recognized that the methods needed to be improved to support current requirements for risk-informed, performance-based (RI/PB) applications. In 2001, EPRI and the NRC's Office of Nuclear Regulatory Research (NRC-RES), operating under a Memorandum of Understanding (MOU), embarked on a cooperative project to improve the state of the art in fire risk assessment to support a new risk-informed environment in fire protection. This project produced a consensus document, NUREG/CR-6850 (EPRI report 1011989)—Fire PRA Methodology for Nuclear Power Facilities—which addressed fire risk for at-power operations. NUREG/CR-6850 developed high-level guidance on the process for identifying human failure events (HFEs) and for including them in the fire PRA. The guidance also defined a process for assigning quantitative screening values to these HFEs. It outlined the initial considerations of performance shaping factors (PSFs) and related fire effects that may need to be addressed in developing best-estimate human error probabilities (HEPs). NUREG/CR-6850 did not, however, describe a method to develop best-estimate HEPs reflecting the PSFs and the fire-related effects. In 2007, EPRI and NRC-RES (again working under the MOU) initiated another cooperative project related to fire PRA to develop explicit guidance for estimating HEPs for HFEs under fire conditions, building on existing human reliability analysis (HRA) methods. This report provides a method and associated guidance for conducting a fire HRA. The process includes the identification and definition of fire HFEs, qualitative analysis, quantification, recovery analysis, dependency analysis, and the treatment of uncertainty. The report also provides three approaches to quantification: screening, scoping, and detailed HRA. Screening is based on the guidance in NUREG/CR-6850, with some additional guidance for scenarios with long time windows. Scoping is a new approach to quantification developed specifically to support the iterative nature of fire PRA quantification. Scoping is intended to provide less conservative HEPs than screening but requires less time and effort than a detailed HRA analysis. For detailed HRA quantification, guidance has been developed on how to apply existing methods to assess fire HEPs.	
2012	NRC (U.S. Nuclear Regulatory Commission). 2012. *Guidance for Performing the Integrated Assessment for Flooding, Draft Interim Staff Guidance.* JLD-ISG-2012-05, Revision 0, Washington, D.C. ML12235A319.	This interim staff guidance (ISG) is being issued to describe to stakeholders methods acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for performing the Integrated Assessment for external flooding as described in NRC's March 12, 2012 request for information (Ref. (1)) issued pursuant to Title 10 of the Code of Federal Regulations (10 CFR) 50.54(f) regarding Recommendation 2.1 of SECY-11-0093, Recommendations for Enhancing Reactor Safety in the 21st Century, the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident (Ref. (2)). Among other actions, the March 12, 2012 letter requests that respondents reevaluate flood hazards at each site and compare the reevaluated hazard to the current design basis at the site for each flood mechanism. Addressees are requested to perform an Integrated Assessment if the current design basis flood hazard does not bound the reevaluated flood hazard for all mechanisms. This ISG will assist operating power reactor respondents and holders of construction permits under 10 CFR Part 50 with performance of the Integrated Assessment. It should be noted that the guidance provided in this ISG is not intended to describe methods for use in regulatory activities beyond the scope of the March 12, 2012, 50.54(f) letter.	
2013	NRC (U.S. Nuclear Regulatory Commission). 2013. *Glossary of Risk-Related Terms in Support of Risk-Informed Decisionmaking.* NUREG–2122, Washington, D.C. ML13311A353.	The policy statement on the "Use of Probabilistic Risk Assessment (PRA) Methods in Nuclear Regulatory Activities" (Ref. 31) expressed the Commission's belief that the use of PRA technology in U.S. Nuclear Regulatory Commission (NRC) regulatory activities should be increased. Consequently, the NRC carried out numerous risk-informed activities in all areas of NRC regulation. With increased risk-informed activities came the recognition that the agency could enhance regulatory stability and efficiency if it implemented the many potential applications of risk information in a consistent and predictable manner. An essential part of consistent and predictable implementation is the use of consistent terminology to ensure accurate communication and transfer of information. Further, the NRC recognizes that some risk-related terms have been used in ambiguous ways by practitioners. The increased development of guidance documents, regulations, and procedures related to risk-informed activities makes the fundamental understanding of these risk-related terms more imperative. Consistent terminology is essential to the appropriate implementation of risk-informed activities and the communication between the NRC and its stakeholders. It allows practitioners to eliminate communication issues and avoid unnecessary discussions that may have been erroneously perceived as technical issues. Therefore, a glossary with agreed-upon definitions of risk-informed related terms is an essential tool for future risk-informed activities. This glossary addresses risk-related terms used in the context of risk associated with a reactor of a nuclear power plant.	
2013	NRC (U.S. Nuclear Regulatory Commission). 2013. *The US HRA Empirical Study – Draft Report, Assessment of HRA Method Predictions against Operating Crew Performance on a U.S. Nuclear Power Plant Simulator.* Washington, D.C. ML13225A516.	This report documents the U.S. Human Reliability Analysis (HRA) Empirical Study (referred to as the U.S. Study in the report), which is a large systematic data collection effort supported by the U.S. Nuclear Regulatory Commission with participation of organizations from five countries representing industry, regulators, and the research community. The objective of the U.S. Study was to improve the insights developed from the International HRA Empirical Study [1–4] (referred to as the International Study) and address the limitations of that study. Similar to the International Study, the U.S. Study evaluated the performance of different HRA methods by comparing method predictions to actual crew performance in simulated accident scenarios conducted in a U.S. nuclear power plant (NPP) simulator. There was significant agreement in the findings and conclusions between the International and U.S. studies in terms of the strengths and weaknesses of the HRA methods evaluated in both studies and in the overall findings about HRA and the identified needed improvements. In addition to identification of some new HRA- and method-related issues, the design of the U.S. Study allowed insights to be obtained on some issues that were not resolved in the International Study. In particular, because multiple HRA teams applied each method in the U.S. Study, comparing their analyses and predictions allowed separation of analyst effects from method effects and allowed conclusions to be drawn on aspects of methods that are susceptible to different application or usage by different analysts that may lead to differences in results. The findings serve as a strong basis for improving the consistency and robustness of HRA, which in turn facilitates identification of mechanisms for improving operating crew performance in NPPs.	

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2014	NRC (U.S. Nuclear Regulatory Commission). 2014. *The International HRA Empirical Study, Lessons Learned from Comparing HRA Methods Predictions to Hammlab Simulator Data.* NUREG–2127, Washington, D.C. ML14227A197.		
2014	NWS (National Weather Service). 2014. Thunderstorms, Tornadoes, Lightning, Nature's Most Violent Storms: A Preparedness Guide, Including Tornado Safety Information for Schools. Available at http://www.lightningsafety.noaa.gov/resources/ttl6-10.pdf.	Lightning safety & preparedness from NWS	Attributes/units and causal factors for Lightning
2011	O'Brien, C., L.A. Blanchard, B.S. Cadarette, T.L. Endrusick, X. Xu, L.G. Berglund, M.N. Sawka, and R.W. Hoyt. 2011. "Methods of Evaluating Protective Clothing Relative to Heat and Cold Stress: Thermal Manikin, Biomedical Modeling, and Human Testing." Journal of occupational and environmental hygiene 8(10):588-599.	PPE must therefore be evaluated to ensure that it poses no greater thermal strain than the current standard for the same level of hazard protection. This review describes how such evaluations are typically conducted.	Contribution by PPE to excess thermal strain.
2007	O'Brien, C., Mahoney, C., Tharion, W. J., Sils, I. V., and Castellani, J. W. (2007).Dietary tyrosine benefits cognitive and psychomotor performance during body cooling. Physiol. Behav. 90, 301–307. doi: 10.1016/j.physbeh.2006.09.027	Supplemental tyrosine is effective at limiting cold-induced decreases in working memory, presumably by augmenting brain catecholamine levels, since tyrosine is a precursor for catecholamine synthesis. The effectiveness of tyrosine for preventing cold-induced decreases in physical performance has not been examined. This study evaluated the effect of tyrosine supplementation on cognitive, psychomotor, and physical performance following a cold water immersion protocol that lowered body core temperature. Fifteen subjects completed a control trial (CON) in warm (35 °C) water and two cold water trials, each spaced a week apart. Subjects ingested an energy bar during each trial; on one cold trial (TYR) the bar contained tyrosine (300 mg/kg body weight), and on the other cold trial (PLB) and on CON the bar contained no tyrosine. Following each water immersion, subjects completed a battery of performance tasks in a cold air (10 °C) chamber. Core temperature was lower ($p = 0.0001$) on PLB and TYR (both 35.5 ± 0.6 °C) than CON (37.1 ± 0.3 °C). On PLB, performance on a Match-to-Sample task decreased 18% ($p = 0.02$) and marksmanship performance decreased 14% ($p = 0.002$), compared to CON, but there was no difference between TYR and CON. Step test performance decreased by 11% ($p = 0.0001$) on both cold trials, compared to CON. These data support previous findings that dietary tyrosine supplementation is effective for mitigating cold-induced cognitive performance such as working memory, even with reduced core temperature, and extends those findings to include the psychomotor task of marksmanship.	
1970	O'Brien, H. W. 1970. Visibility and Light Attenuation in Falling Snow. Journal of Applied Meteorology 9, 671-683.	The attenuation of visible light by failing snow was studied by making simultaneous determinations of attenuation coefficients and snow concentration. The attenuation coefficient was calculated from photo-metric measurements and from visual observations. Snow concentration in the air was evaluated by two methods. Formal replicas collected during the snowfall, and mass accumulation of snow in collecting pans. The snowflakes were arbitrarily classified by crystal types according to their estimated fall velocity. It was found that the correlation between extinction coefficient and snow concentration was generally much higher by types than when all snowflakes were considered together regardless of crystal components and degree of riming. When no fog is present during the snowfall, the experimental results for some snow types coincide well with attenuation theory if a reasonable correction is applied to the values obtained in the measurement of snow-flake diameters. Measurements of mass flux indicate that for a given intensity the attenuation caused by snow is an order of magnitude greater than that caused by the same mass flux of rain.	work that relies on distance vision outdoors (e.g., surveying, monitoring outdoor security cameras) may be rendered difficult or inaccurate due to the light attenuation effects of precipitation
2009	O'Hara, J. 2009. Applying Human Performance Models to Designing and Evaluating Nuclear Power Plants: Review Guidance and Technical Basis. BNL-90676-2009). Upton, NY: Brookhaven National Laboratory.	Describes the use of human performance models like IMPRINT in the design of NPPs.	Approach and process for implementing IMPRINT and similar HPMs
2007	O'Brien, C., Tharion W.J., Sils I.V., Castellani, J.W. Cognitive, psychomotor, and physical performance in cold air after cooling by exercise in cold water. Aviat Space Environ Med 2007; 78:568–73.	Studied physical and mental performance with lowered core temp by placed into cold water immersion.	Body temp fell, cognitive remained unchanged but physical ability decreased by 12%.
1992	O'Brien, L.H., R. Simon, and H. Swaminathan. 1992. "Development of the Personnel-Based System Evaluation Aid (PER-SEVAL) Performance Shaping Functions. ARI Research Note 92-50. Prepared by Dynamics Research Corporation for the U.S. Army Research Institute for the Behavioral and Social Sciences. June, 1992. Alexandria, Virginia. www.dtic.mil/dtic/tr/fulltext/u2/a252820.pdf.	PER-SEVAL model intended to aid in identifying personnel characteristics that will meet system performance requirements given fixed values for conditions, training, and design.	Precursor to IMPRINT - 1992
1992	O'Hara, J.M., and R.E. Hall. 1992. "Advanced Control Rooms and Crew Performance Issues: Implications for Human Reliability." Nuclear Science, IEEE Transactions on 39(4):919-923.	Recent trends in advanced control room (ACR) design are considered with respect to their impact on human performance. It is concluded that potentially negative influences exist, however, a variety of factors make it difficult to model, analyze, and quantify these effects for human reliability analyses (HRAs).	Theoretical paper describing the negative effects of computer systems design on cognition, especially wrt control rooms.

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2006	Oksa, J., H. Rintamaki, and T. Makinen. 2006. "The Effect of Training of Military Skills on Performance in Cold Environment." *Military Medicine* 171:757–61.	Study of the effects of cold on military-specific manual actions - fine motor.	Directly relevant to Cold effects on fine motor skills.
2014	Oliveira, A.V.M., A.R. Gaspar, J.S. André, and D.A. Quintela. 2014. "Subjective Analysis of Cold Thermal Environments." Applied Ergonomics 45(3):534-543. http://www.sciencedirect.com/science/article/pii/S0003687013001531.	The present work is dedicated to the study of cold thermal environments in food distribution industrial units through a subjective assessment based on an individual questionnaire which aims to describe the working conditions of employees often exposed to cold. 79.6% of the workers report that working in the cold is harder in wintertime. The results also highlight that 37.3% of the workers report having health problems.	Working in cold environment increases the perceived difficulty of work performed.
1922	Osborne, E. E., & Vernon, H. M. (1922). Two Contributions to the Study of Accident Causation: The Influence of Temperature and Other Conditions on the Frequency of Industrial Accidents (Report No. 19). Medical Research Council, Industrial Fatigue Research Board.		
2016	OSHA (Occupational Safety and Health Administration). 2016a. Safe winter driving. United States Department of Labor, Washington, DC. Accessed November 9, 2016 at https://www.osha.gov/Publications/SafeDriving.pdf	OSHA fact sheet for driving safety in snow/ice	Mitigations for snow/ice
2016	OSHA (Occupational Safety and Health Administration). 2016b. Hazard Alert: Falls and Other Hazards to Workers Removing Snow from Rooftops and Other Elevated Surfaces. United States Department of Labor, Washington, DC. Accessed November 9, 2016 at: https://www.osha.gov/Publications/OSHA-3513roof-snow-hazard.pdf	OSHA snow/ice injury fact sheet.	Includes background on Ice/Snow accident risk.
2012	Paddan, G.S., S.R. Holmes, N.J. Mansfield, H. Hutchinson, C.I. Arrowsmith, S.K. King, R.J.M. Jones, and A.N. Rimell. 2012. "The Influence of Seat Backrest Angle on Human Performance During Whole-Body Vibration."	This study investigated the effects of reclined backrest angles on cognitive and psycho-motor tasks during exposure to vertical whole-body vibration.	Vibration related performance impact
1977	Pandolf, K.B., Givoni, B., Haisman, B. and Goldman, R.F. 1977. Predicting Energy Expenditure with Loads while Standing or Walking Very Slowly. Journal of Applied Physiology 43(4):577-581.	Examined energy expenditure of soldiers walking at different rates with a variety of pack weights.	Includes functions for energy expenditure in snow.
1985	Pandolf, K.B., L.A. Stroschein, L.L. Drolet, R.R. Gonzalez, and M.N. Sawka. 1985. "Prediction Modeling of Physiological Responses and Human Performance in the Heat." Computers in biology and medicine 16(5):319-329.	This paper presents the mathematical basis employed in the development of the various individual predictive equations of their heat stress model.	Includes predictive equations for deep body temperature, heart rate and sweat loss responses of clothed soldiers performing physical work at various environmental extremes, including Heat and Cold.
2008	Parasuraman, R., and Wilson, G.F. 2008. Putting the Brain to Work: Neuroergonomics Past, Present, and Future. Human Factors 50(3):468-474.	The authors describe research and applications in prominent areas of neuroergonomics. Because human factors/ergonomics examines behavior and mind at work, it should include the study of brain mechanisms underlying human performance. Neuroergonomic studies are reviewed in four areas: workload and vigilance, adaptive automation, neuroengineering, and molecular genetics and individual differences. Neuroimaging studies have helped identify the components of mental workload, workload assessment in complex tasks, and resource depletion in vigilance. Furthermore, real-time neurocognitive assessment of workload can trigger adaptive automation. Neural measures can also drive brain-computer interfaces to provide disabled users new communication channels. Finally, variants of particular genes can be associated with individual differences in specific cognitive functions. Neuroergonomics shows that considering what makes work possible - the human brain - can enrich understanding of the use of technology by humans and can inform technological design. Applications of neuroergonomics include the assessment of operator workload and vigilance, implementation of real-time adaptive automation, neuroengineering for people with disabilities, and design of selection and training methods.	
1993	Parent, J.S. 1993. The Impact of Combined Heat and Noise on Short-Term Retention. DTIC Document.	Masters thesis - lit review of Heat and Noise individually, and includes a study examining interactive effects of 105 degree and 94db noise exposure on short term recall.	Interactive effects of Heat and Noise on memory.

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2014	Parmentier, F. B. (2014). The cognitive determinants of behavioral distraction by deviant auditory stimuli: A review. Psychological Research, 78(3), 321-338.	Numerous studies have demonstrated that rare and unexpected changes in an otherwise repetitive or structured sound sequence ineluctably break through selective attention and impact negatively on performance in an unrelated task. While the electrophysiological responses to unexpected sounds have been extensively studied, behavioral distraction has received relatively less attention until recently. In this paper, I review work examining the cognitive underpinnings of behavioral distraction by deviant sounds and highlight some of its key determinants. Evidence indicates that deviance distraction (1) derives from the time penalty associated with the involuntary orientation of attention to and away from the deviant sound and from resulting effects such as the reactivation of the relevant task set upon the presentation of the target stimulus; and (2) is mediated by a number of factors (some increasing distraction, such as aging or induced emotions; some decreasing it, such as a memory load or cognitive control). Contrary to the received view that deviants ineluctably elicit distraction, recent work demonstrates that it is contingent upon auditory distractors acting as unspecific warning signals in the service of goal oriented behavior, and that deviants do not elicit distraction because they are rare but because they violate the cognitive system's predictions (which can be manipulated through implicit rule learning or explicit cueing). Evidence is also presented indicating that the capture of attention by spoken deviant sounds is followed by an involuntary evaluation of their semantic properties, the outcome of which can be robust enough to linger in working memory and interfere with subsequent behavior. Finally, I review studies suggesting that behavioral deviance distraction is not the mere byproduct of the mismatch negativity, P3a and re-orientation negativity electrophysiological responses and highlight a number of outstanding questions for future research.	
1982	Parry, M. Skin Temperature and Motorcyclists Braking Performance. Perceptual and Motor Skills.1982. 54.1291-1296	Studied manual performance to apply braking at normal temps (27.8C) vs cooled hand temps (6C).	Significant decrement in performance for cooled hands
2014	Parsons, K. (2014). Human thermal environments: the effects of hot, moderate, and cold environments on human health, comfort, and performance (3rd ed). Boca Raton, Fl: CRC Press.	The book covers hot, moderate, and cold environments, and defines them in terms of six basic parameters: air temperature, radiant temperature, humidity, air velocity, clothing worn, and the person's activity. It focuses on the principles and practice of human response, which incorporates psychology, physiology, and environmental physics with applied ergonomics. The text then discusses water requirements, computer modeling, computer-aided design, and current standards. A systematic treatment of thermal environments and how they affect humans in real-world applications, the book links the health and engineering aspects of the built environment. It provides you with updated tools, techniques, and methods for the design of products and environments that achieve thermal comfort.	
1995	Patil, P. G., Apfelbaum, J. L., and Zacny, J. P. (1995). Effects of a cold-water stressor on psychomotor and cognitive functioning in humans. Physiol. Behav. 58, 1281–1286.	The effects of an acute stressful and painful stimulus, cold water, on psychomotor and cognitive functioning, was assessed in 14 healthy volunteers. Subjects immersed their forearm in ice-cold water (2-3 degrees C) and luke-warm water (37 degrees C) for 3 min, and during this time period a psychomotor or cognitive test was performed. These immersions were done over the course of two experimental sessions, spaced at least 2 days apart, with six trials in each session. Within each session, cold and warm water immersions alternated. Results indicated that flicker-from-fusion threshold from the critical flicker frequency test was higher in the cold-water condition than in the luke-warm-water condition, indicative of increased alertness from the cold stimulus. Short-term memory was attenuated, however, in the cold-water condition. Performance on other tests including those that required speed and/or concentration were not affected by the manipulation. Subjects rated the cold-water stimulus as painful and bothersome, and their blood pressure was significantly elevated by the stimulus. We conclude that a painful stimulus may affect psychomotor and/or cognitive functioning, but the relationship is somewhat complex and depends on the particular tests used.	
2012	Paul, M. (2012). Psycho-motor analysis of athletes under overtraining stress. Serbian Journal of Sports Sciences, 6(3).	The purpose of the present study was to compare and investigate the relation between the scores in the Training Stress Scale, Reboundability Subscale and Psychomotor Performance as assessed by the Motor Performance Series in the Vienna Test System. The total of 100 athletes (65 males, 35 females) from various sports was divided into three stress groups: High Stress Group (HSG), Moderate Stress Group (MSG), and Low Stress Group (LSG) according to the Training Stress Scale scores. One-way ANOVA indicated a significant difference among the three groups for the Training Stress Scale ($p<0.001$), Reboundability (Resilience) Subscale ($p<0.001$), and various parameters of psychomotor performance. The study concluded that the athletes' resilience (reboundalibity) to mistakes decreased with increasing stress levels. Also, the HSG showed poor psychomotor performance in the Motor Performance Series. However, optimal stress levels and proper physiological and psychological training can counteract the negative effects of training and non-training stress.	
2015	Paulauskas, H., M. Brazaitis, D. Mickeviciene, K. Pukenas, and N. Eimantas. 2015. "Acute Cold Stress and Mild Hypothermia Impact on Short-Term, Working Memory and Attention." *Bioloogija* 61(1):1–14.	Effects of a single acute cold water exposure on the cognitive function (short-term, working memory and attention) was examined in 25 male subjects	Effect of Cold and Standing Water effect on men
2012	Paulsen, M., T.J. Alicia, and D.M. Shrader. 2012. "Modeling Algorithms for Predicting the Effects of Human Performance in the Presence of Environmental Stressors." *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 56(1):975-979.	The purpose of this paper is to describe an approach for developing performance shaping function (PSF) algorithms for environmental stressors that can be integrated into human performance modeling tools.	Potential framework for quantification of environmental stress impacts

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2009	Paulus, M.P., Potterat, E.G., Taylor, M.K., van Orden, K.F., Bauman, J., Momen, N., Padilla, G., Swain, and J.L. 2009. A Neuroscience Approach to Optimizing Brain Resources for Human Performance in Extreme Environments. Neuroscience and Biobehavior Review 33(7):1080-1088.	Extreme environments requiring optimal cognitive and behavioral performance occur in a wide variety of situations ranging from complex combat operations to elite athletic competitions. Although a large literature characterizes psychological and other aspects of individual differences in performances in extreme environments, virtually nothing is known about the underlying neural basis for these differences. This review summarizes the cognitive, emotional, and behavioral consequences of exposure to extreme environments, discusses predictors of performance, and builds a case for the use of neuroscience approaches to quantify and understand optimal cognitive and behavioral performance. Extreme environments are defined as an external context that exposes individuals to demanding psychological and/or physical conditions, and which may have profound effects on cognitive and behavioral performance. Examples of these types of environments include combat situations, Olympic-level competition, and expeditions in extreme cold, at high altitudes, or in space. Optimal performance is defined as the degree to which individuals achieve a desired outcome when completing goal-oriented tasks. It is hypothesized that individual variability with respect to optimal performance in extreme environments depends on a well "contextualized" internal body state that is associated with an appropriate potential to act. This hypothesis can be translated into an experimental approach that may be useful for quantifying the degree to which individuals are particularly suited to performing optimally in demanding environments.	
2009	Pearsall, M. J., Ellis, A. P., & Stein, J. H. (2009). Coping with challenge and hindrance stressors in teams: Behavioral, cognitive, and affective outcomes. Organizational Behavior and Human Decision Processes, 109(1), 18-28.	The purpose of this study was to utilize the challenge–hindrance framework to examine the discrete and combined effects of different environmental stressors on behavioral, cognitive, and affective outcomes at the team level. Results from 83 teams working on a command and control simulation indicated that the introduction of a challenge stressor positively affected team performance and transactive memory. The introduction of a hindrance stressor negatively affected team performance and transactive memory and positively affected psychological withdrawal. When the hindrance stressor was combined with the challenge stressor, teams exhibited the lowest levels of performance and transactive memory, and the highest levels of psychological withdrawal. These effects were due to the adoption of specific coping strategies by team members. Implications are discussed, as well as limitations and directions for future research.	
2005	Penning-Rowsell, E., P. Floyd, D. Ramsbottom, and S. Surendran. 2005. "Estimating Injury and Loss of Life in Floods: A Deterministic Framework." *Natural Hazards* 36(1-2):43-64. http://search.proquest.com/docview/755140171?accountid=26501.	This paper presents an outline methodology and an operational framework for assessing and mapping the risk of death or serious harm to people from flooding	Potential framework for quantification of environmental stress impacts
2002	Perrin, J., Martin, P.T., and Hansen, B.G. 2002. Modifying Signal Timing During Inclement Weather. Institute for Transportation Engineers. Annual Meeting and Exhibit Compendium of Papers, Philadelphia, PA, August.	paper examines automobile traffic effects of Snow, and uses the parameters for developing signal timings during inclement weather conditions	Relevant to Ice/Snow effects on automobile operation.
2012	Petersen, S.E., and Posner, M.I. 2012. The Attention System of the Human Brain: 20 Years After. Annual Review of Neuroscience 35:73-89.	Here, we update our 1990 Annual Review of Neuroscience article, "The Attention System of the Human Brain." The framework presented in the original article has helped to integrate behavioral, systems, cellular, and molecular approaches to common problems in attention research. Our framework has been both elaborated and expanded in subsequent years. Research on orienting and executive functions has supported the addition of new networks of brain regions. Developmental studies have shown important changes in control systems between infancy and childhood. In some cases, evidence has supported the role of specific genetic variations, often in conjunction with experience, that account for some of the individual differences in the efficiency of attentional networks. The findings have led to increased understanding of aspects of pathology and to some new interventions	
1994	Petrenko, V. F. 1994. The Effect of Static Electric Fields on Ice Friction. Journal of Applied Physics 76(2):1216-1219.	Experiment and discussion about how static electricity may play a significant role in forming the ice friction coefficient and that the friction can be modified intentionally.	Good review of physics of slippage on ice/snow
2011	Pharmer, J.A., M. Paulsen, and T.J. Alicia. 2011. Validating Environmental Stressor Algorithms for Human Performance Models. Naval Air Warfare Center Training Systems Division.	Paper describes the development of an approach for validating Performance Shaping Function (PSF) algorithms for predicting individual (e.g., motion, vibration, temperature) and interactive effects (e.g., motion and vibration together) of environmental stressors on human performance.	These algorithms were used in the development of IMPRINT taxon effects.
2000	Phetteplace, G. 2000. "Integrating Cold Weather Impacts on Human Performance into Army M&S Applications." in Simulation Conference, 2000. Proceedings. Winter, Vol 1, pp. 1020-1024 vol.1021.	This study discusses how performance is reduced in terms of both time to perform a given task and accuracy, during exposure to cold	Performance degradation from thermal (cold) stress
2007	Pilcher, J.J., Band, D., Odle-Dusseau, H.N., Muth, E.R. Human Performance Under Sustained Operations and Acute Sleep Deprivation Conditions: Toward a Model of Controlled Attention. Aviat Space Environ Med 2007; 78(5, Suppl.):B15–24.	The purpose of the current study was to examine the effects of sustained operations and acute sleep deprivation on tasks that require a wide range of information processing.	Performance degradation associated with fatigue
2002	Pilcher, J.J., E. Nadler, C. Busch, and J.A. Volpe. 2002. "Effects of Hot and Cold Temperature Exposure on Performance: A Meta-Analytic Review." *Ergonomics* 45(10):682-698.	A meta-analysis to mathematically summarize the effect of hot and cold temperature exposure on performance.	Performance impact from thermal environmental stressors

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2007	Pinkard, F., T. Pratt, D. Ward, T. Holmes, J. Kelley, L.T. Lee, G. Sills, E. Smith, P.A. Taylor, N. Torres, L. Wakeley, and J. Wibowo. 2007. *Flood-Fighting Structures Demonstration and Evaluation Program: Laboratory and Field Testing in Vicksburg, Mississippi.* ERDC TR-07-3, U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.	Discussion about sandbagging and other flood-fighting barriers typically used during flood mitigation and response.	Provides context for the type of work flood mitigation workers may be performing.
2003	Pisano, P., L. Goodwin, and A. Stern. 2003. Surface Transportation Safety and Operations: The Impacts of Weather with the Context of Climate Change. Proceedings of the U.S. Department of Transportation Center for Climate Change Workshop: The Potential Impacts of Climate Change on Transportation, October 2002. Available at: http://climate.dot.gov/documents/workshop1002/pisano.pdf. Orig cited in text as FHWA 2002	Surface transportation is the dominant method of moving people and commerce in the United States. Services supporting surface transportation require usable infrastructure and effective systems. Primary highway operational goals—safety, mobility and productivity—are affected by environmental conditions. Weather acts through visibility impairments, precipitation, high winds, temperature extremes, and lightning to affect driver capabilities, vehicle maneuverability, pavement friction, and roadway infrastructure. The Road Weather Management Program of the Federal Highway Administration (FHWA) has documented operational practices of traffic, maintenance, and emergency managers employed under various weather threats and the weather information needs of travelers. This paper examines weather impacts on roadways, operational practices of transportation managers and road users, and the weather parameters with the greatest effects on roadways. Finally, a discussion of how possible climate change may affect these parameters during the next century is presented.	Long range potential for climate change on surface transportation safety
2008	Pisano, P.A., L.C. Goodwin, and M.A. Rossetti. 2008. "Us Highway Crashes in Adverse Road Weather Conditions." in 24th Conference on International Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology, New Orleans, LA.	This paper presents statistics on weather-related crashes, injuries, and fatalities on U.S. highways from 1995 to 2005. The paper also examines weather exposure and severity, driver behavior and traffic flow in inclement weather, regional variance in crash types and rates, and the economic impacts of weather-related crashes. The paper concludes with a discussion of documented crash mitigation strategies that have safety benefits, as well as research needs to better understand the nature of the problem and explore improved mitigation strategies.	Good review of weather (e.g., Ice/Snow/Rain) effects on accident rates.
2013	Pomeroy, D. 2013. The Impact of Stressors on Military Performance. Defense and Technology Organization - Australian Government - Department of Defense	Large literature review - with a lot of info	Covers many topics. Very good info
2012	Pond, T.J. 2012. *Discrete Event Simulation of Distributed Team Communication.* Air Force Institute of Technology, 58 pp http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA558299.	Masters thesis - examines effects on remote vehicle pilot workload of control architecture using IMPRINT	Example of using IMPRINT to determine cognitive effects of modifying interfaces.
2014	Popević, M. B., S. M. Janković, S.S. Borjanović, S.R. Jovičić, L. R. Tenjović, A.P. Milovanović, and P. Bulat. 2014. Assessment of coarse and fine hand motor performance in asymptomatic subjects exposed to hand-arm vibration. Archives of Industrial Hygiene and Toxicology, 65(1), 29-36.	Studied population with early hand-arm vibration syndrome vs control group for dexterity and grip strength	Dexterity was reduced but grip strength remained the same.
2013	Poplawski, ME and Miller, NM. 2013. Flicker in Solid-State Lighting: Measurement Techniques, and Proposed Reporting and Application Criteria. DOE-PNNL-SA-94791. Portland, OR.	Solid-state lighting is already bringing energy-efficiency, excellent color, long life, controllability, unique optics and forms to architectural lighting. However, the flicker found in some SSL systems can be a significant barrier to adoption. Furthermore, the pairing of dimming controls with SSL sources can increase flicker, or even induce it in sources that do not flicker in switched mode. Flicker has been shown to induce photosensitive epilepsy, migraines and headaches, and increased autistic behaviors in certain people. Reduced task performance, stroboscopic or phantom array motion effects, distraction, and annoyance are other possible consequences. Modulation depth, frequency, and waveform shape have been shown to affect flicker sensitivity, and are known to be dependent upon exposure time and a number of visual factors. Yet, flicker is rarely reported in product literature, and there is little to no guidance for architectural lighting practitioners in applying LED products that may flicker. The authors have developed a means for measuring and reporting lighting flicker. The data analysis techniques are presented, as well as measurements from many conventional and SSL products operated using simple switches and dimming controls. Using data from previous and current flicker research, a straw-person standard is proposed based on flicker index and flicker frequency. Guidelines are presented to help guide practitioners in their evaluation of lighting products and conversations about flicker with manufacturers and clients.	
1965	Poulton, E. C., & Kerslake, D. (1965). Initial stimulating effect of warmth upon perceptual efficiency. Aerospace Medicine, 36, 29-32.		
2015	Power, J., A. Simões Ré, M. Barwood, P. Tikuisis, and M. Tipton. 2015. "Reduction in Predicted Survival Times in Cold Water Due to Wind and Waves." Applied Ergonomics 4918-24. http://www.sciencedirect.com/science/article/pii/S0003687015000022.	Two immersion suit studies, one dry and the other with 500 mL of water underneath the suit, were conducted in cold water with 10e12 males in each to test body heat loss under three environmental conditions: calm, as mandated for immersion suit certification, and two combinations of wind plus waves to simulate conditions typically found offshore. In both studies mean skin heat loss was higher in wind and waves vs. calm; deep body temperature and oxygen consumption were not different. Mean survival time predictions exceeded 36 h for all conditions in the first study but were markedly less in the second in both calm and wind and waves. Immersion suit protection and consequential predicted survival times under realistic environmental conditions and with leakage are reduced relative to calm conditions.	Water immersion in windy conditions can increase body heat loss even with protective clothing, presumably reducing performance.

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2013	Pray, M. C. 2013. Some like It Mild and Not Too Wet: The Influence of Weather on Subjective Well-Being. Journal of Happiness Studies 14:457-473.	More and more economists and politicians are advocating the use of comprehensive measures of well-being, on top of the usual national accounting measures, to assess the welfare of populations. Researchers using subjective well-being data should be aware of the potential biasing effects of the weather on their estimates. In this paper, the responsiveness of well-being to climate and transitory weather conditions is investigated by analyzing subjective well-being data collected in the Princeton Affect and Time Survey. General satisfaction questions about life in general, life at home, health and one's job, as well as questions concerning feelings intensities during specific episodes are studied. Women are much more responsive than men to the weather, and life satisfaction decreases with the amount of rain on the day of the interview. Low temperatures increase happiness and reduce tiredness and stress, raising net affect, and high temperatures reduce happiness, consistent with the fact that the survey was conducted in the summer. Methods to reduce the possible biases are suggested in the conclusion.	Precipitation, or at least the weather characteristics associated with precipitation (e.g., cloudiness, wind), also appears to have a negative effect on mood and well-being
2010	Proctor, R. W. & Vu, K.-P. L. (2010). Cumulative knowledge and progress in human factors. Annual Review of Psychology, 61, 623-651.	This review provides a cumulative perspective on current human factors research by first briefly acknowledging previous Annual Review articles. We show that several recent conceptual advances are an outgrowth of the information-processing approach adopted by the field and present several areas of current research that are built directly on prior work. Topic areas that provide fundamental tools for human factors analyses are summarized, and several current application areas are reviewed. We end by considering alternatives to the information-processing approach that have been proposed and placing those alternatives in context. We argue that the information-processing language provides the foundation that has enabled much of the growth in human factors. This growth reflects a cumulative development of concepts and methods that continues today.	
1970	Provins, K. A., & Bell, C. R. (1970). Effects of heat stress on the performance of two tasks running currently. Journal of Experimental Psychology, 85, 40-44.	20 19-47 yr. old male Ss performed a 5-choice serial RT task at each of 2 pacings while watching for infrequent light signals from 6 different parts of the visual field in both cool (20–/15– C dry bulb/wet bulb) and hot (40–/35– C dry bulb/wet bulb) environmental conditions. An initially beneficial effect of heat on performance of the fast-paced serial RT task was lost with continued exposure to heat, but no climatic effect was found on performance of the visual vigilance task. Results are discussed in terms of arousal and are considered to support the view that the effect of heat exposure on perceptual-motor performance is more directly related to body temperature than the climatic conditions.	
2012	PSEG (PSEG Nuclear LLC). 2012. "Letter from C.J. Fricker to NRC, Dated December 26, 2012, Regarding "Loss of Circulating Water and Manual Reactor Trip Due to Hurricane Sandy."." ML13002A004.	Hurricane Sandy effects on NPP operations.	Report of incidents at NPP associated with Hurricane Sandy.
2013	Qian S., Sun G., Jiang Q., Liu K., Li B., Li M., et al. . (2013). Altered topological patterns of large-scale brain functional networks during passive hyperthermia. Brain Cogn. 83, 121–131.	In this study, we simulated environmental heat exposure to 18 participants, and obtained functional magnetic resonance image (fMRI) data during resting state. Brain functional networks were constructed over a wide range of sparsity threshold according to a prior atlas dividing the whole cerebrum into 90 regions. Results of graph theoretical approaches showed that although brain networks in both normal and hyperthermia conditions exhibited economical small-world property, significant alterations in both global and nodal network metrics were demonstrated during hyperthermia. Specifically, a lower clustering coefficient, maintained shortest path length, a lower small-worldness, a lower mean local efficiency were found, indicating a tendency shift to a randomized network. Additionally, significant alterations in nodal efficiency were found in bilateral gyrus rectus, bilateral parahippocampal gyrus, bilateral insula, right caudate nucleus, bilateral putamen, left temporal pole of middle temporal gyrus, right inferior temporal gyrus. In consideration of physiological system changes, we found that the alterations of normalized clustering coefficient, small-worldness, and mean normalized local efficiency were significantly correlated with the rectal temperature alteration, but failed to obtain significant correlations with the weight loss. More importantly, behavioral attention network test (ANT) after MRI scanning showed that the ANT effects were altered and correlated with the alterations of some global metrics (normalized shortest path length and normalized global efficiency) and prefrontal nodal efficiency (right dorsolateral superior frontal gyrus, right middle frontal gyrus and left orbital inferior frontal gyrus), implying behavioral deficits in executive control effects and maintained alerting and orienting effects during passive hyperthermia. The present study provided the first evidence for human brain functional disorder during passive hyperthermia according to graph theoretical analysis using resting-state fMRI.	
2006	Qian, X., and J. Fan. 2006. "Interactions of the Surface Heat and Moisture Transfer from the Human Body under Varying Climatic Conditions and Walking Speeds." Applied Ergonomics 37(6):685-693. http://www.sciencedirect.com/science/article/pii/S0003687006000135.	In this paper, through the experimental measurements on a newly developed sweating/nonsweating fabric manikin (named WALTER) under varying climatic conditions and 'walking'' speeds, authors show that the surface thermal insulation is little affected by moisture transfer.	Interactive effects of Cold and moisture on moisture transfer to clothing.
1988	Quinn, P.J. 1988. "Effects of Temperature on Cell Membranes." *Symposium of Social Experimental Biology* 42:237-258	Describes the effects of temperature perturbations on cellular biology.	Basic cellular biology effects of Heat - mechanism of action for higher-level effects.
1966	Ramaswamy, S. S., Dua, G. L., Raizada, V. K., Dimri, G. P., Viswanathan, K. R., Madhaviah, J., and Srivastava, T. N. 1966. Effect of Looseness of Snow on Energy Expenditure in Marching on Snow-covered Ground. Journal of Applied Physiology, 21, 1747-1749.		Effects of Snow on gross motor skills.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1995	Ramsey, J. D. 1995. "Task Performance in Heat: A Review." *Ergonomics* 38(1):154-165.	A wide array of variable conditions, tasks, subject populations, etc., have been included in studies that have produced data on perceptual motor performance in the heat. This paper uses a methodology for comparing these studies, regardless of the inherent differences, which allows determination of whether thermal effects are dominant enough to persist through diverse combinations of variables. Approximately 160 individual studies of perceptual motor performance reported in the literature were summarized based on thermal level, duration of exposure and the type of task performed. Results indicated no dominant effect of duration of exposure to the heat and no dominant effect of thermal level on mental/cognitive tasks. For perceptual motor tasks other than very simple or mental tasks, an onset of performance decrement was noted in the 30-33 degrees C WBGT range of temperature. This temperature level is consistent with the Recommended Exposure Limits for work in the heat at low levels of metabolic heat.	Classical attempt to clarify the underlying causes of conflicting research results, separated the effects of heat on cognitive performance by whether the task was simple or complex.
1975	Ramsey, J. D. (1975). Heat and cold. In G.R.J. Hockey (Ed.), Stress and Fatigue in Human Performance (pp. 30-60). Chichester, UK: John Wiley & Sons, Ltd.		
1992	Ramsey, J. D. and Y.G. Kwon. 1992. Recommended alert limits for perceptual motor loss in hot environments. International Journal of Industrial Ergonomics, 9. 245-257.	Research concerning the effects of heat on task performance has been extensive and contradictory. This paper summarizes over a hundred and fifty studies where performance has been reported as a function of temperature, exposure time and type of task. It suggests that prediction of performance loss first requires categorizing the type of tasks since mental or very simple tasks typically show little decrement in the heat and are frequently enhanced during brief exposures. Other perceptual motor tasks collectively depict a pattern of onset of performance decrement in the 30°C–33°C WBGT temperature range, and the decrement appears to be relatively independent of exposure time. This is the same temperature range as that associated with the onset of physiological heat stress for the worker performing sedentary or very light work. It appears that performance decrement may be better explained by body temperatures, as indicated by the head or blood temperature, than by the deep body temperature.	
1978	Ramsey, J.D. and Morrissey, S.J. 1978. "Isodecrement Curves for Task Performance in Hot Environments." *Applied Ergonomics* 9(2):66-72	This paper proposes a set of isodecrement curves for performance of perceptual motor tasks as a function of temperature and exposure time. Tasks studied include reaction time, mental tasks, vigilance, tracking, complex tasks, and combination of these tasks.	
1983	Ramsey, J.D., C.L. Burford, M.Y. Beshir, and R.C. Jensen. 1983. "Effects of Workplace Thermal Conditions on Safe Work Behavior." *Journal Safety Research* 14:105-114	The effect of workplace thermal conditions on worker safety has not previously been adequately investigated, due in part to the difficulty of defining a suitable safety performance measure. This report describes a study conducted in two industrial plants to determine if a correlation exists between the safety-related behavior of workers and workplace thermal conditions. Both heat exposure measurements and behavioral observations were taken over a 14-month period, for a total of over 17,000 observations. The results indicate that temperatures below and above those typically preferred by most people have a significantly detrimental effect on the safety-related behavior of workers. This is demonstrated by an index based on the ratio of observed unsafe behaviors to the total number of observed behaviors. The relationship between this index of unsafe behavior and the ambient temperature formed an U-shaped curve. The minimum unsafe behavior index occurred within the zone of preferred temperature (approximately 17°C to 23°C, WBGT). Other factors such as metabolic workload and time during the shift also had significant effects on worker safety-related behavior.	Classical report relating unsafe behaviors to temperature -- noted a U-shaped relationship with errors minimized in relative comfort zone: ~17-23 deg C
2012	Rashedi, E., Jia, B., Nussbaum, M. A., and Lockhart, T. E. 2012. Investigating the Effects of Slipping on Lumbar Muscle Activity, Kinematics, and Kinetics. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 56(1):1201–1205.	Slips, trips, and falls remain leading causes of occupational injuries and fatalities. The current exploratory study quantified lumbar kinematics and kinetics during both induced slips and normal walking. Individual anthropometry, lumbar muscle geometry, and lumbar kinematics, along with electromyography of 14 lumbar muscles were used as input to a 3D, dynamic, EMG-based model of the lumbar spine. Results indicated that, in comparison with values during normal walking, lumbar kinematics, lumbosacral kinetics, lumbar muscle activations, and lumbosacral reaction forces were all substantially increased during a slip event. Observed levels of muscle activity and lumbosacral reaction forces suggest the potential for low back injury during a slip event. Outcomes of this work may facilitate the identification and control of specific mechanisms involved with low back disorders consequent to a slip.	). Even when workers are able to react in time to avoid a fall, they often injure their lower back as a result of the movements made trying to regain balance
2001	Redfern, M., Cham, R., Gielo-Perczak, K., Gronqvist, R., Hirvonen, M., Lanshammar, H., Marpet, M., Pai, C. Y. C., and Powers, C. 2001. Biomechanics of Slips. Ergonomics 44(13):1138-1166.	The biomechanics of slips are an important component in the prevention of fall-related injuries. The purpose of this paper is to review the available literature on the biomechanics of gait relevant to slips. This knowledge can be used to develop slip resistance testing methodologies and to determine critical differences in human behavior between slips leading to recovery and those resulting in falls. Ground reaction forces at the shoe-floor interface have been extensively studied and are probably the most critical biomechanical factor in slips. The ratio of the shear to normal foot forces generated during gait, known as the required coefficient of friction (RCOF) during normal locomotion on dry surfaces or 'friction used/achievable' during slips, has been one biomechanical variable most closely associated with the measured frictional properties of the shoe/floor interface (usually the coefficient of friction or COF). Other biomechanical factors that also play an important role are the kinematics of the foot at heel contact and human responses to slipping perturbations, often evident in the moments generated at the lower extremity joints and postural adaptations. In addition, it must be realized that the biomechanics are dependent upon the capabilities of the postural control system, the mental set of the individual, and the perception of the environment, particularly, the danger of slipping. The focus of this paper is to review what is known regarding the kinematics and kinetics of walking on surfaces under a variety of environmental conditions. Finally, we discuss future biomechanical research needs to help to improve walkway-friction measurements and safety.	Slip-and-fall risk appear to be influenced by awareness of the potential slipperiness, and when aware of an ice patch, workers usually take defensive actions, e.g. shortening strides, slowing speed, and stepping more flat-footed. This reduces the forces at work between footwear and the ice or snow thereby increasing the effective COF and helping to avoid a slip.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1969	Reicher, G.M. 1969. Perceptual recognition as a function of meaningfulness of stimulus material. Journal of Experimental Psychology 81:275-280.	The present study evaluates a class of models of human information processing made popular by Broadbent. A brief tachistoscopic display of one or two single letters, four-letter common words, or four-letter nonwords was immediately followed by a masking field along with two single-letter response alternatives chosen so as to minimize informational differences among the tasks. Giving 5s response alternatives before the stimulus display as well as after it caused an impairment of performance. Performance on single words was clearly better than performance on single letters. The data suggest that the first stages of information processing are done in parallel, but scanning of the resultant highly processed information is done serially.	Effects of vibration may be partially overcome by the by the word-superiority effect (letters in words more recognizable if embedded in a word)
2000	Richman J. B., B. P. Dyre and L. Fournier. 2000. "Allocation of Attention Affects Perceived Heading Direction with Transparent Flow Fields." Proceedings of the Human Factors and Ergonomics Society Annual Meeting 44(21):3-415-3-418.	In two experiments, they examined: a) whether transparent radial expansion patterns that accompany observer motion and specify heading direction are subject to such errors, b) whether attentional 'allocation to different motion components affects these errors, and c) whether these errors can result in inappropriate control input. We found that significant errors in perception of heading direction do occur for transparent radial expansion patterns, that attentional allocation influences these errors, and that these errors result in inappropriate control input.	Mechanism of action for Snow effects on driving performance
2015	Richmond, P.W., A.W. Potter, and W.R. Santee. 2015. Terrain factors for predicting walking and load carriage energy costs: Review and refinement. J Sport Human Perf 3(3):1-26.	The ability to predict the energy cost of load carriage is important to various disciplines and applications including anthropology, exercise physiology, humanitarian aid, and dismounted military operations. Energy consumption in turn determines the physiological status of individuals and populations and their ability to function via internal heat production, hydration, fatigue, and caloric intake. Various parameters of the physical environment, including topographic relief and surface conditions impact those energy costs. To be comprehensive, predictive load carriage cost models must incorporate body mass, load, positive and negative grades, and adjustments for surface conditions. Models developed at the U.S. Army Research Institute of Environmental Medicine (USARIEM) in the 1970s incorporated an adjustment for surface conditions, i.e. a terrain factor. However, the terrain factors were derived empirically from data for a relatively limited set of surface conditions or classes. Aside from efforts to apply the classification of terrain factors to a broader set of conditions, little work has been done on to improve terrain factors since the 1970s. This paper reviews the effect of terrain properties on locomotion, the development of terrain factors, and provides scientific improvements based on the parallel studies of vehicular trafficability at the U.S. Army Cold Regions Research Engineering Laboratory (CRREL).	Presents contemporary predictive model of terrain factors effects on walking and carriage, building on a historical review -- with factors for differing surfaces (pavement to hard snow).
2011	Roberts, J. E. 2011. Ultraviolet radiation as a risk factor for cataract and macular degeneration. Eye & Contact Lens 37(4):246-249.	The human eye is constantly exposed to sunlight and artificial lighting. Light transmission through the eye is fundamental to its unique biological functions of directing vision and circadian rhythm, and therefore, light absorbed by the eye must be benign. However, exposure to the intense ambient radiation can pose a hazard particularly if the recipient is over 40 years of age. This radiation exposure can lead to impaired vision and transient or permanent blindness. Both ultraviolet-A (UV-A) and UV-B induce cataract formation and are not necessary for sight. Ultraviolet radiation is also a risk factor for damage to the retinas of children. The removal of these wavelengths from ocular exposure will greatly reduce the risk of early cataract and retinal damage. One way this may be easily done is by wearing sunglasses that block wavelengths below 400 nm (marked 400 on the glasses). However, because of the geometry of the eye, these glasses must be wraparound sunglasses to prevent reflective UV radiation from reaching the eye. Additional protection may be offered by contact lenses that absorb significant amounts of UV radiation. In addition to UV radiation, short blue visible light (400-440 nm) is a risk factor for the adult human retina. This wavelength of light is not essential for sight and not necessary for a circadian rhythm response. For those over 50 years old, it would be of value to remove these wavelengths of light with specially designed sunglasses or contact lenses to reduce the risk of age-related macular degeneration.	Delineates UV risks for developing macular degeneration and cataracts.
2014	Rodriguez, J. M., Codjoe, J., Osman, O., Ishak, S., & Wolshon, B. (2014b). Experimental modeling of the effect of hurricane wind forces on driving behavior and vehicle performance. Journal of emergency management (Weston, Mass.), 13(2), 159-172.	While traffic planning is important for developing a hurricane evacuation plan, vehicle performance on the roads during extreme weather conditions is critical to the success of the planning process. This novel study investigates the effect of gusty hurricane wind forces on the driving behavior and vehicle performance. The study explores how the parameters of a driving simulator could be modified to reproduce wind loadings experienced by three vehicle types (passenger car, ambulance, and bus) during gusty hurricane winds, through manipulation of appropriate software. Thirty participants were then tested on the modified driving simulator under five wind conditions (ranging from normal to hurricane category 4). The driving performance measures used were heading error and lateral displacement. The results showed that higher wind forces resulted in more varied and greater heading error and lateral displacement. The ambulance had the greatest heading errors and lateral displacements, which were attributed to its large lateral surface area and light weight. Two mathematical models were developed to estimate the heading error and lateral displacements for each of the vehicle types for a given change in lateral wind force. Through a questionnaire, participants felt the different characteristics while driving each vehicle type. The findings of this study demonstrate the valuable use of a driving simulator to model the behavior of different vehicle types and to develop mathematical models to estimate and quantify driving behavior and vehicle performance under hurricane wind conditions.	
2015 (cited as 2014b)	Rodriguez, J. M., J. Codjoe, O. Osman, S. Ishak, and B. Wolshon. 2015. Experimental modeling of the effect of hurricane wind forces on driving behavior and vehicle performance. J. Emerg. Manag. 13(2)159-172.	While traffic planning is important for developing a hurricane evacuation plan, vehicle performance on the roads during extreme weather conditions is critical to the success of the planning process. This novel study investigates the effect of gusty hurricane wind forces on the driving behavior and vehicle performance. The study explores how the parameters of a driving simulator could be modified to reproduce wind loadings experienced by three vehicle types (passenger car, ambulance, and bus) during gusty hurricane winds, through manipulation of appropriate software. Thirty participants were then tested on the modified driving simulator under five wind conditions (ranging from normal to hurricane category 4). The driving performance measures used were heading error and lateral displacement. The results showed that higher wind forces resulted in more varied and greater heading error and lateral displacement. The ambulance had the greatest heading errors and lateral displacements, which were attributed to its large lateral surface area and light weight. Two mathematical models were developed to estimate the heading error and lateral displacements for each of the vehicle types for a given change in lateral wind force. Through a questionnaire, participants felt the different characteristics while driving each vehicle type. The findings of this study demonstrate the valuable use of a driving simulator to model the behavior of different vehicle types and to develop mathematical models to estimate and quantify driving behavior and vehicle performance under hurricane wind conditions.	Explored gust hurricane wind force effects on control of car, ambulance and bus control using LSU simulator -- indicating control at Category 1 but rapid decline at higher levels

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2014	Rodriguez, J.M. 2014. Modeling the Effect of Gusty Hurricane Wind Force on Vehicles Using the LSU Driving Simulator. Master's Thesis, MSCE, Louisiana State University, Baton Rouge, LA.	While traffic planning is important for developing a hurricane evacuation plan, vehicle performance on the roads during extreme weather conditions is critical to the success of the planning process. This study was designed to lay a foundation for modeling driving behavior and vehicle performance as an assessment tool in the decision making process for planning evacuation routes during hurricane and tropical storms. The study explores how the parameters of a driving simulator could be modified to reproduce wind loadings experienced by three vehicle types (a passenger car, an ambulance, and a bus) during gusty hurricane winds, through manipulation of appropriate software. Thirty participants were then tested on the modified driving simulator under five wind conditions (ranging from "wind-free" to hurricane category 4). The driving performance measures used were heading error and lateral displacement. The results showed that higher wind forces resulted in more varied and greater heading error and lateral displacement. The ambulance had the greatest heading errors and lateral displacements, which were attributed to its large lateral surface area and light weight. Mathematical models were developed to estimate the heading error and lateral displacements for each of the vehicle types for a given change in lateral wind force. Through a questionnaire, participants felt the different Characteristics while driving each vehicle type. The findings of this study demonstrate the valuable use of a driving simulator to model the behavior of different vehicle types, and to develop mathematical models to estimate and quantify driving behavior and vehicle performance under hurricane wind conditions.	Explored gust hurricane wind force effects on control of car, ambulance and bus control using LSU simulator -- indicating control at Category 1 but rapid decline at higher -- greater levels -- modeling emphasis in Thesis
2008	Roeder, W. P. (2008). Recent Updates in Lightning Safety. 20th International Lightning Detection Conference, Tucson, AZ.	Lightning is the second leading cause of storm related deaths in the United States, only floods kill more (NOAA, 2007). Lightning kills more than tornadoes or hurricanes (Figure 1). Lightning also inflicts life-long debilitating injury on many more than it kills (Cooper, 1995). Lightning is also a significant weather hazard outside of the U.S. (Holle and Lopez, 2003). Fortunately, most lightning casualties can be easily, quickly, and cheaply prevented. Public education is the key.	
2012	Roeder, W. P., Holle, R. L., Cooper, M. A., & Hodanish, S. (2012, April). Lessons learned in communicating lightning safety effectively. In 4th international lightning meteorology conference, Broomfield, CO, Vaisala.	Lightning is a leading source of storm deaths in the United States (NOAA, 2009). Fortunately, most lightning casualties in the U.S. can be prevented easily, quickly, and cheaply. Public education is the key. However, that public education needs to be communicated effectively. Lightning safety requires the same two basic elements as any public education effort. First, the public must be motivated to learn the information. Second, the information taught must be effective. In addition, the message must be clear and easy to remember in a stressful situation such as when lightning threatens. As in most communications, tailoring the message to the audience is critical.	
2011	Rossetti, M. A., and Johnsen, M. 2011. Impacts of Climate Change and Weather on Commercial Motor Vehicles. FMCSA-RRA-11-013. Cambridge, MA: US Department of Transportation: Volpe National Transportation Systems Center.	Observed climatic patterns represent the averages and variability of long term weather conditions. These patterns result from the interactions of oceanic, geologic, and solar influences, the atmospheric concentrations of various gases and aerosols, and other factors. Various studies now indicate that the planet is getting warmer and that this global warming is beginning to impact regional weather patterns and thus weather-sensitive sectors of the economy (AMS 2007). As part of these impacts, climate change can produce both economic gains and economic gains and losses (IPCC 2007 and Changnon 2005). Commercial motor vehicles (CMVs) include trucks with a gross vehicle weight rating of >10,001 lbs, as well as most types of buses. The study period for which CMV data are available is 1975 to the present. Exposure to adverse weather may occur at any point in distribution supply chain and cause ripple effects in the intermodal transportation system. This paper looks at a specific problem area from the transportation sector, the role of different types of weather events as risk factors in CMV crashes and performance. This includes the possible role of climate change in increasing the distribution, frequency or severity of those weather events and their impacts on measures such as safety and delay.	Overlaps occasionally with others by same authors over years. Important study reported: Reminding and encouraging workers to exercise special caution when working in precipitation by double-checking work products, following safety procedures, wearing appropriate and reflective clothing, and reducing speed when driving or operating heavy machinery have been found to moderate the effects of precipitation on accident rates
2008	Rossetti, M.A., and M. Johnsen. 2008. "Impacts of Weather and Climate on Commercial Motor Vehicles." in American Meteorological Society 20th Conference on Climate Variability and Change.	The Federal Motor Carrier Administration (FMCSA) sponsored this work as part of its responsibilities to reduce the number and severity of CMV crashes and enhance the efficiency of CMV operations. This study is to improve understanding of the how weather and climate forces affect CMV safety. It examines trends and factors in weather-related CMV crashes, and potential mitigation measures to reduce weather-related crashes. It also evaluates external programs such as improved observation and detection systems, more accurate and precise models, and better weather forecasts. Average temperatures have been found to show a positive association with vehicle deaths, and precipitation a negative association (Loeb 2007). Although only about 16 percent of all fatal CMV crashes are associated with adverse weather or wet pavement, that share can still have significant effects on vehicle performance and safety as well systemic effects that may impact other modes and economic sectors.	Overlaps with others by same authors, however, first among reviewed noting: airflow underneath bridges, bridge road surfaces tend to freeze more rapidly than surface roads, producing sudden changes between wet and icy pavement, which can produce a significant loss in control of the vehicle and thus injury and death. This is especially problematic for black ice, which blends visually with the pavement, thereby preventing awareness (similar to ice-covered snow when walking) and consequently, caution. This can produce catastrophic loss of control
1996	Royden C.S., Hildreth, E.C. 1996. Human Heading Judgments in the Presence of Moving Objects. Perceptual Psychophysiology 58(6):836–856.	When moving toward a stationary scene, people judge their heading quite well from visual information alone. Much experimental and modeling work has been presented to analyze how people judge their heading for stationary scenes. However, in everyday life, we often move through scenes that contain moving objects. Most models have difficulty computing heading when moving objects are in the scene, and few studies have examined how well humans perform in the presence of moving objects. In this study, we tested how well people judge their heading in the presence of moving objects. We found that people perform remarkably well under a variety of conditions. The only condition that affects an observer's ability to judge heading accurately consists of a large moving object crossing the observer's path. In this case, the presence of the object causes a small bias in the heading judgments. For objects moving horizontally with respect to the observer, this bias is in the object's direction of motion. These results present a challenge for computational models.	

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1996	Royden C.S., Hildreth, E.C. 1996. Human Heading Judgments in the Presence of Moving Objects. Perceptual Psychophysiology 58(6):836–856.	When moving toward a stationary scene, people judge their heading quite well from visual information alone. Much experimental and modeling work has been presented to analyze how people judge their heading for stationary scenes. However, in everyday life, we often move through scenes that contain moving objects. Most models have difficulty computing heading when moving objects are in the scene, and few studies have examined how well humans perform in the presence of moving objects. In this study, we tested how well people judge their heading in the presence of moving objects. We found that people perform remarkably well under a variety of conditions. The only condition that affects an observer's ability to judge heading accurately consists of a large moving object crossing the observer's path. In this case, the presence of the object causes a small bias in the heading judgments. For objects moving horizontally with respect to the observer, this bias is in the object's direction of motion. These results present a challenge for computational models.	One of several reports that directional precipitation, especially snowfall, can produce this induced motion effect and systematic heading judgment errors in driving simulators
2011	Ruby, B.C. 2011. *Evaluation of the Human/Extreme Environment Interaction: Implications for Enhancing Operational Performance and Recovery.* Annual Report, University of Montana, Missoula, Montana.	The purpose of this research determines how hypoxia interacts with exercise and recovery to yield various metabolic responses that may affect performance and performance at high-altitude critical to mission success.	Performance impacts associated with high elevation or otherwise hypoxic environment
2014	Ruby, B.C. 2014. *Evaluation of the Human-Extreme Environment Interaction: Implications for Enhancing Operational Performance and Recovery.* Final Report, University of Montana, Missoula, Montana.	Multi-year study update on performance effects at high-altitude	Performance impacts associated with high elevation or otherwise hypoxic environment
2013	Russo, B., M. Gómez, and F. Macchione. 2013. "Pedestrian Hazard Criteria for Flooded Urban Areas." *Natural Hazards* 69(1):251-265.	Study discusses stability of pedestrians in flooded street during storm events. Empirical expressions were proposed to relate human subject characteristics (weight and height) and limiting flow conditions at which loss of stability occurs.	Model for human instability in flood water
2014	Sabri, M., C. Humphries, M. Verber, E. Liebenthal, J.R. Binder, J. Mangalathu, and A. Desai. 2014. Neural effects of cognitive control load on auditory selective attention. Neuropsychologia 61:269–279.	Whether and how working memory disrupts or alters auditory selective attention is unclear. We compared simultaneous event-related potentials (ERP) and functional magnetic resonance imaging (fMRI) responses associated with task-irrelevant sounds across high and low working memory load in a dichotic-listening paradigm. Participants performed n-back tasks (1-back, 2-back) in one ear (Attend ear) while ignoring task-irrelevant speech sounds in the other ear (Ignore ear). The effects of working memory load on selective attention were observed at 130-210ms, with higher load resulting in greater irrelevant syllable-related activation in localizer-defined regions in auditory cortex. The interaction between memory load and presence of irrelevant information revealed stronger activations primarily in frontal and parietal areas due to presence of irrelevant information in the higher memory load. Joint independent component analysis of ERP and fMRI data revealed that the ERP component in the N1 time-range is associated with activity in superior temporal gyrus and medial prefrontal cortex. These results demonstrate a dynamic relationship between working memory load and auditory selective attention, in agreement with the load model of attention and the idea of common neural resources for memory and attention.	Glare and/or insufficient lighting have the potential for adverse cross-modal effects, although there is no consensus about the specific mechanisms by which this occurs
1982	Salamé, P. and A.D. Baddeley. 1982. Disruption of short-term memory by unattended speech: Implications for the structure of working memory. Journal of Verbal Learning and Verbal Behavior 21:150-164.	A series of experiments studied the effect of unattended speech on immediate memory for visually presented digits. Memory performance showed clear impairment, with the degree of impairment being a function of the phonological similarity of the irrelevant words to the visually presented digits. In contrast, the semantic characteristics of the unattended speech did not influence performance. Requiring the subject to suppress articulation removed the disrupting effect of irrelevant speech. These results are interpreted in terms of two separate memory systems of which one relies on a phonological code. The system is accessible in two ways, through auditory presentation leading to obligatory registration of the material, or through an optional subvocal rehearsal process.	Speech noise effects on performance are so ubiquitous they have been named "the irrelevant speech effect" (i.e., impaired recall in the presence of verbal noise that is irrelevant to the task at hand)
2001	Salvi, L. 2001. Development of Improved Performance Research Integration Tool (Imprint) Performance Degradation Factors for the Air Warrior Program. DTIC Document.	The Human Research and Engineering Directorate of the U.S. Army Research Laboratory examined the effects of clothing and individual equipment (CIE) and aircrew life support equipment (ALSE) on the performance of Army aviators. These efforts were quantified in terms of the additional time needed to perform certain types of tasks as a direct result of the equipment and ensembles. Through the completion of detailed questionnaires by subject matter experts, estimates of performance were collected and analyzed, and a set of performance degradation factors was developed. The methodology was developed in concert with the modeling tool IMPRINT, in order to predict the effects of CIE and ALSE on mission- and system-level performance. The methodology demonstrated success in converting otherwise subjective data into a quantifiable and generalizable modeling approach.	One consideration in modeling is the potential trade-off between performance measures especially between accuracy and speed -- and how to model.
1999	Sauter, D., M. Torres, J. Brandt, and S. McGee. 1999. "Integrated Weather Effects Decision Aid: A Common Software Tool to Assist in Command and Control Decision Making."		
2016	Savage, R., D. Billing, A. Furnell, K. Netto, and B. Aisbett. 2015. Whole-Body Vibration and Occupational Physical Performance: A Review. International Archives of Occupational and Environmental Health 89(2):181-197.	In the occupational environment, there are a considerable number of stressors that can affect physical performance in job tasks. Whole-body vibration (WBV), which arises from vehicle transit, is one such stressor that has been demonstrated to alter human function in several ways. This study identifies the known physical changes to human function which result from WBV, to comment on changes which may translate to performance in physically demanding occupational tasks. A systematic review is performed on the literature relating to changes in the neuromuscular, physiological and biomechanical properties of the human body, when exposed to WBV. Selection criteria are constructed to synthesize articles which strictly relate to in-vehicle WBV and physical responses. In total, 29 articles were identified which satisfied the criteria for inclusion. A range of physical responses produced from WBV are presented; however, little consistency exists in study design and the responses reported. Given the inconsistency in the reported responses, the precise changes to human function remain unknown. However, there is sufficient evidence to warrant the design of studies which investigate occupationally relevant physical performance changes following WBV.	Vibration exposure effects may continue after a stimulus ceases (particularly if chronic).

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2006	Saxton, B.M., J.M. Ross, A. Braczyk, G.E. Conway, J.L. Szalma, and P.A. Hancock. 2006. *A Meta-Analysis of Aperiodic Noise Stress on Human Performance.* ADA482011.	Aperiodic noise, also known as intermittent noise, is a pervasive and influential source of stress across military environments, and can be defined by the changes in its intensity over a given period of time (therefore containing `gaps' between louder phases of the noise). With examples ranging from the discharge of weapons to vehicle and machinery movements, then it is intuitive to recognize that this common form of noise may constitute a risk to Soldier performance across a range of tasks (i.e., as measured by speed and accuracy metrics). In order to quantify these effects, a meta-analytic evaluation of aperiodic noise effects on performance was undertaken. The results indicate that a general effect of aperiodic noise is to exert a negative influence on performance; however this effect is contingent upon the type of tasks and performance measures used. These results can be used to inform decisions concerning when noise should be mitigated or even alternatively exploited in military settings.	
989	Scheffer, M., Dupuis, H. 1989. Effects of combined hand-arm vibration and cold on skin temperature. Int Arch Occup Environ Health (1989) 61: 375-378.	Hand-arm vibration was tested at temps 5, 12, 18 and 25C. Static load (grip force 15 N, push force 40 N) was constant. Low temp (5, 12 and 18C) cause a strong decrease of skin temp. Vibration stress caused a further decrease of mean skin temp. Static load proved a major influence on the acute diminution of skin temp. Field tests with a chain saw at low temps showed results similar to laboratory tests.	Lower temps did play a role in hand grip ability.
1998	Schipani, S. P., Bruno, R. S., Lattin, M. A., King, B. M., & Patton, D. J. (1998). Quantification of cognitive process degradation while mobile, attributable to the environmental stressors endurance, vibration, and noise, ARL-TR-1603. US Army Research Laboratory, Aberdeen Proving Ground, MD. available at http://www.dtic.mil/docs/citations/ADA346416.	Operator cognitive performance was quantified in an off-road environment by repeatedly administering a battery of cognitive measures to assess the genus and degree of performance while mobile. Environmental stressors referred to as endurance, tracked vehicle vibration per intensity, and noise were recorded over the course of one day per participant (n=18). Vibration conditions presented were varying amplitudes approximating accelerations of 0.88 g by a frequency of 3 cycles per second (cps), 0.65 g by 4 cps, and 0.03 g by 12.5 cps. Observed collectively, the predictor variables returned a multiple R value for the dependent variable percent correct of 0.733 ($p < .0001$) and for the dependent time to complete of 0.649 ($p < .0001$). Although all stressors significantly influenced performance, uncovered was a repeated order of effect per method of evaluation, beginning with the measure endurance, then session, followed by absorbed power recordings, then exposure limit criteria comparison, and finally, noise. Cognitive performance decrement measured as percent correct was found for the cognitive concepts time sharing, selective attention, inductive reasoning, spatial orientation, speed of closure, and memorization. Measured as percent of time taken to complete tests, degradation was found for the concepts speed of closure, time sharing, inductive reasoning, spatial orientation, selective attention, and memorization. This investigation displayed the existence of dose response relationships, higher doses of vibration associated with more unfavorable effects. Additionally, the trials effect recorded indicates that performance deteriorated as a function of time in the environment.	Showed decrements in time-sharing, memorization, inductive reasoning, attention, and spatial orientation after vibration ceased (i.e., continuing after effects).
2015	Schlittmeier, S.J., Feil, A., Liebl, A., and Hellbrück, J. 2015. The Impact of Road Traffic Noise on Cognitive Performance in Attention-Based Tasks Depends on Noise Level Even within Moderate-Level Ranges. Noise and Health 17(76):148-157.	Little empirical evidence is available regarding the effects of road traffic noise on cognitive performance in adults, although traffic noise can be heard at many offices and home office workplaces. Our study tested the impact of road traffic noise at different levels (50 dB(A), 60 dB(A), 70 dB(A)) on performance in three tasks that differed with respect to their dependency on attentional and storage functions, as follows: The Stroop task, in which performance relied predominantly on attentional functions (e.g., inhibition of automated responses; Experiment 1: n = 24); a non-automated multistage mental arithmetic task calling for both attentional and storage functions (Exp. 2: n = 18); and verbal serial recall, which placed a burden predominantly on storage functions (Experiment 3: n = 18). Better performance was observed during moderate road traffic noise at 50 dB (A) compared to loud traffic noise at 70 dB (A) in attention-based tasks (Experiments 1-2). This contrasted with the effects of irrelevant speech (60 dB (A)), which was included in the experiments as a well-explored and common noise source in office settings. A disturbance impact of background speech was only given in the two tasks that called for storage functions (Experiments 2-3). In addition to the performance data, subjective annoyance ratings were collected. Consistent with the level effect of road traffic noise found in the performance data, a moderate road traffic noise at 50 dB(A) was perceived as significantly less annoying than a loud road traffic noise at 70 dB(A), which was found, however, independently of the task at hand. Furthermore, the background sound condition with the highest detrimental performance effect in a task was also rated as most annoying in this task, i.e., traffic noise at 70 dB(A) in the Stroop task, and background speech in the mental arithmetic and serial recall tasks.	Many of (in this case highway) noise's effects on performance may -- as with several other ECs -- be tied to its observed tendency to produce arousal, stress, and annoyance that affects an individual's ability to focus attention on the task at hand
2016	Schneider, R., S Visweswaran, J. Fluehr, and H.A. Hackerott. 2016. Guidance for Human Action Evaluations for External Flood Risk Assessment. In Proceedings of ICONE24 24th International Conference on Nuclear Engineering, June 26-30, 2016 Charlotte, North Carolina, USA.	The purpose of this paper is to define the challenges in defining an approach for treating external flood actions, identifying external flood timelines, identifying the manual actions/organizational environment during external flooding scenarios and proposing an integrated strategy for quantifying those actions. The proposed quantification process is rooted in management science concepts for evaluating project reliability. The overall methodology identifies flood significant performance shaping factors, and identifies three (3) factors, namely time available for flood mitigation, proper access to plant site following flood and environmental factors, as having an overarching impact on the performance shaping factors affecting each of the flood mitigation tasks.	
1976	Schultz, T. J., Galloway, W. J., Beland, D., and Hirtle, P. W. (1976). Recommendations for changes in HUD's noise policy standards, Washington, DC, Department of Housing and Urban Development.		
2007	Seah, W. K., & Tan, G. H. (2007, November). Wireless multihop networks in mission critical realtime monitoring and alerts for construction sites. In Proc. of the 3rd International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-3), Vancouver, BC, Canada (pp. 13-16).	In major construction projects involving extensive excavation and tunneling, it is crucial to have accurate realtime monitoring to ensure that support structures are not excessively stressed as these could lead to collapse and fatalities. The integration of machine-to-machine (M2M) technologies has been proposed to improve the process of transferring data from the sensors in the monitoring sites to be promptly processed into information that can assist engineers in handling unexpected events. While the use of M2M technologies in the construction industry has been increasing, much more can be exploited from wireless communications to improve the productivity levels and more importantly the safety aspects. In this paper, we present a realtime monitoring and alert system integrated with a multihop wireless network. Besides replacing the wiring which can pose significant problems in a construction site, wireless communications also makes the system less vulnerable to lightning and other problems. With the wireless transmission devices located near the sensors, we reduce the wiring substantially and using a multihop architecture enables us to extend the communication range by relaying data from one radio to another until the on-site data logger.	

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12	See, J. E. 2012. Visual Inspection: A review of the literature. Sandia National Laboratories, New Mexico, SAND2012-8590.	This report provides a review of 212 documents published in the visual inspection literature from the 1950s to the present. The inspection task is defined and characterized and trends in inspection research are reviewed. The prevailing two component model of inspection and various techniques to measure inspection performance are discussed. The majority of the report reviews the parameters that may impact inspection performance and describes the relevant findings from the literature. The report concludes with a re-iteration of the value of inspection research and a summary of the major recommendations for improving inspection performance.	Reviews lighting-illumination parameters that may impact inspection
1988	Seidel, H., Harazin, B., Pavlas, K., Sroka, C., Richter, J., Blüthner, R. & Rothe, R. (1988). Isolated and combined effects of prolonged exposures to noise and whole-body vibration on hearing, vision and strain. International archives of occupational and environmental health, 61(1-2), 95-106.	This study was carried out in order: (1) to examine the effects of isolated and combined prolonged exposures to noise and whole-body vibration on hearing, vision and subjectively experienced strain, and (2) to check the combined effects with repeated exposures. Six male subjects were exposed twice to noise (N) at 92 dBA, whole-body vibration (V) in the Z-axis at 4 Hz and 1.0 ms-2 rms, and noise and vibration (NV) for 90 min with each condition. Temporary threshold shifts of hearing (TTS) and their integrals (ITTS) were measured at 4, 6, 10, and 12 kHz. Visual acuity was examined by means of a very sensitive test. Cross-modality matching (CMM) of the handgrip force was used to judge the subjectively experienced strain. NV induced a clear tendency of higher TTS and ITTS than N, with several significant differences most pronounced at 10 kHz. With repeated exposures, the effect of NV decreased, while the reactions to N and V remained unchanged. The individual reactions to NV differed. The influence of the duration of exposures on vision depended on the condition; N caused time-dependent changes, whereas V did not. CMM-data increased with the duration of the exposure during V and NV. N was generally judged to be more straining than V; NV caused higher strain than V during the first 30 min of exposure only. Correlations between different effects suggest certain links between them. Additionally, less motivation--daily obtained by a questionnaire--often correlated with higher ITTS during N and NV. The results also illustrate the combined effects on the individual susceptibility, repetition of exposure, the kind of response, and, possibly, the actual psychic state.	
2006	Sharp, M., M. Rosenberger, and J. Knapik. 2006. Common Military Task: Materials Handling. DTIC Document.	Lifting and lifting and carrying (L-L&C) tasks are the most common physically demanding tasks performed by the Armed Force of many NATO nations. These tasks contribute to overexertion injuries, particularly low back pain and disability. This review of the literature describes published recommendations for safe loads, the use of teamwork to reduce the load, equations used to predict the energy cost of L-L&C tasks, methods used by NATO nations to evaluate L-L&C performance and training methods to improve L-L&C task performance.	
2008	Sheridan, T.B. 2008. "Risk, Human Error, and System Resilience: Fundamental Ideas." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 50(3):418-426. http://hfs.sagepub.com/content/50/3/418.abstract.	Author reviews and critiques basic ideas of both traditional error/risk analysis and the newer and contrasting paradigm of resilience engineering.	Context to infer valid probabilities of human error to input to quantitative models
1992	Sherwood, N. and M.J. Griffin. 1992. Evidence of impaired learning during whole-body vibration. Journal of Sound and Vibration 152:219-225.	A study of the effects of whole-body vibration on learning and memory was conducted, in which a context-dependent experimental design was used. Forty subjects completed a simple associative learning task, half during exposure to 16 Hz whole-body sinusoidal vertical vibration at 2.0 m s−2 r.m.s. and half while static. The results show that the rates of learning of the two groups differed, with that of the vibrated subjects significantly impaired. A second session, one week later, indicated that information learnt in one vibration environment could be recalled equally well in a different environment, suggesting no context-dependent effects on memory processes.	Showed immediate learning impaired during vibration, but later delayed recall appeared unimpaired.
1998	Shimizu, T., Kosaka, M., Fujishima, K. Human thermoregulatory responses during prolonged walking in water at 25, 30 and 35C. Eur J Appl Physiol (1998) 78: 473-478	Studied exercising for 1 hour in temp adjusted water to correspond to 50% maximal oxygen uptake. Monitored oxygen consumption and heart rate. Rectal and skin temp were calculated for mean skin temp.	Skin temp and heart rate rose sharply at 35C. At 25C there was a large increase in mean skin and rectal temp for treadmill in air compared to in water
2003	Shintani, Y., Hara, F., Fukumoto, A., and Akiyama, T. 2003. Empirical Study on Walking Behavior in Icy Conditions and the Effect of Measures to Improve the Winter Pedestrian Environment. In: Transportation Research Board 82nd Annual Meeting. Washington, DC.	Over the past few decades, the City of Sapporo has made its urban infrastructure more resistant to cold and snow. Nevertheless, since studless tires started prevailing over studded tires, the number of slip and fall accidents in winter has rapidly increased due to the emergence of extremely icy slippery roads. Besides, pedestrians are wearing shoes and apparel less suitable for conditions of cold and snow, in response to the physical improvements. In light of this, the city would exhaust its resources if it were obliged to eradicate snow and ice from the city so that people could enjoy a snow- and ice-free environment like that in summer. To meet the demands of residents without excessive non-physical or physical improvements, it is important to determine what measures and what levels of service the city should provide for an improved pedestrian environment. A walking experiment under winter conditions was conducted to analyze pedestrian walking characteristics and the effects of anti-slip shoes and gravel spreading on an icy road, measures that are easy for any party to adopt at relatively low cost. The results showed that gravel spreading afforded no improvement of friction coefficient. However, gravel spreading did afford anti-slip effects, as shown by the relatively stable walking observed on the flat or less steep icy surface with gravel. In addition, gravel spreading enhanced the sense of security of the subjects more than did the use of anti-slip shoes.	Supports minimum 0.2 COF but also has supported general finding that participants claimed they felt safer on graveled ice than when wearing anti-slip shoes, despite the fact that the COF was lower on graveled ice (and thus the slip danger was arguably greater)
2009	Shirkey, R. 2009. Risk Levels for Rule-Based Weather Decision Aids. DTIC Document.	Rules-based weather effects decision aids, such as the Tri-Service Integrated Weather Effects Decision Aid (T-IWEDA), is a "stop-light" type of decision aid. The rules that T-IWEDA uses for differentiating the stop-light boundaries do not sufficiently represent real-world conditions. Within each T-IWEDA band (red/yellow/green) significant variation may occur. According to Army FM-34-81-1, Battlefield Weather Effects, moderate impacts (yellow regions) cover from 25 to 75% reduced normal effectiveness. Within such a large region it is unrealistic to believe that there is not a further gradation of impacts, i.e. a slow transition from red to green, rather than three abrupt, unvarying regions. To mitigate this problem a series of weather specific curves, that transition from red to yellow to green in a continuous manner, have been developed using measured and modeled resources. Parametric curves have been developed for IR sensors, helicopters, and personnel working under varied weather conditions. For a given or forecast weather condition, these curves can be used to represent the level of risk for select systems, sub-systems or components. The technique and curves are applicable for TIWEDA and may also be used as a "penalty" within combat models.	

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2016	Shounak, G. H. A. (2016). Extension of activity analysis methodology to maintenance, shutdown, and turnarounds in petrochemical facilities (Doctoral dissertation). Austin, TX: University of Texas, Austin.	Studies show that construction productivity has been stagnant for decades. Interestingly, other industries like manufacturing, automobile and agriculture have witnessed a steep increase in productivity, nearly twice, over the same period of time. It has been the norm for many continuous improvement methods, employed by these industries, to claim credit for this trend. While inadequacies in a range of parameters like management practices, organizational behavior, contractual differences, and other planning functions affect poor productivity, the first step towards any improvement program is to measure the existing condition. The importance of measuring and improving productivity has become increasingly critical and significant with raging project capital costs and complexity, especially in the petroleum industry. This research focusses on providing a productivity language for petrochemical owners and contractors. The developed methodology helps them to communicate improvement strategies with each other and within their organization beyond construction leading into maintenance and shutdown turnarounds. Activity Analysis is a productivity assessment and improvement method developed by the Construction Industry Institute (CII) in 2010. This thesis describes the adaptation of activity analysis methodology that was developed to measure productivity indicators at petrochemical facilities on construction, maintenance and shutdown turnaround activities between 2015 and 2016. It also provides an overview on the activity analysis software developed for data collection, which is a byproduct of this research. This study also provides a summary of expected trends and challenges in petrochemical industries, and strategies that could be implemented to enhance the direct work rate in both construction and maintenance environment.	
1994	Shurtleff, D., Thomas, J. R., Schrot, J., Kowalski, K., and Harford, R. (1994). Tyrosine reverses a cold-induced working-memory deficit in humans. Pharmacol. Biochem. Behav. 47, 935–941.	Acute exposure to cold stress has been shown to impair short-term, or working, memory, which may be related to reduction in, or disruption of, sustained release of brain catecholamines. Administering a supplemental dose of the catecholamine precursor tyrosine may alleviate cold stress-induced memory impairments by preventing cold-induced deficits in brain catecholamine levels. The present experiment determined whether administration of tyrosine would prevent a cold-induced working memory deficit, using a computer-based delayed matching-to-sample (DMTS) memory task. Eight male volunteers performed the DMTS task for 30 min at an ambient temperature of either 4 degrees C (cold) or 22 degrees C following a 30-min preexposure period and 2 h after ingesting 150 mg/kg of L-tyrosine or placebo. Subjects demonstrated a decline in matching accuracy on the DMTS task as delay interval increased, such that matching accuracy following a 16-s delay between sample and comparison stimuli was lower than that following a delay of 2 or 8 s. Consistent with previous research, and relative to 22 degrees C exposure sessions, matching accuracy during 4 degrees C exposure sessions was reduced significantly following placebo administration, which is attributed to the effect of cold exposure on short-term, or working, memory. Administration of tyrosine significantly improved matching accuracy at the longest delay interval most affected by cold exposure, such that matching accuracy in the cold following tyrosine was at the same level as matching accuracy following placebo or tyrosine administration at 22 degrees C. Tyrosine administered prior to 22 degrees C exposure had no effect on DMTS performance.	
2010	Sillitoe, A., Upcraft, D., Rich, K., LaRoche, M., Røed, B., & Huse, J. 2010. Supporting human performance in ice and cold conditions. Lloyd's Register, London. Presented at the Human Performance at Sea Conference held in Glasgow, United Kingdom, May 2010. https://www.sjofartsdir.no/PageFiles/7937/HPAS%202010_IMAREST%202011.pdf. This paper on Human Behavior for the Polar Code CG Website was originally presented at the Human Performance at Sea Conference held in Glasgow, United Kingdom, in May 2010. A presentation based on the paper was delivered at the IMarEST Arctic Shipping and Offshore Technology Forum in October 2011.	Hazards and performance influencing factors. Spray icing occurs forward on a ship • Atmospheric icing • Hazardous operational issues: Stability and maneuverability, Weather and light conditions • Reduced visibility • Sea states, cyclonic conditions, “Polar lows” • Ice conditions change at short notice • Extremes of daylight and darkness • Glare • Ultraviolet light • Access and operability to equipment and systems • Slips, trips and falls • De-icing - ice removal	
2010	Simon, Y.L. 2010. *The Effects of Personal Protective Equipment Level a Suits on Human Task Performance.* MS, Engineering Management, Missouri University of Science and Technology, 76 pp. http://scholarsmine.mst.edu/cgi/viewcontent.cgi?article=5993&context=masters theses.		
1985	Smith, A.P. 1985. Noise, biased probability and serial reaction. Br. J. Psychol. 76(Pt 1):89-95.	Recent studies have shown that moderate intensity noise does influence performance although most studies showing effects of this level of noise have used verbal materials. An experiment showed that moderate intensity noise (85 dBC) also influences attentional selectivity in a serial reaction task which involved the processing of sensory information. Noise decreased response times to signals with high probabilities of occurrence but increased latencies for signals which occurred less frequently. Although attentional selectivity in noise depended on signal probability, it was not influenced by the spatial location of the signal. When a mode of responding is adopted in noise, subjects are often rather inflexible and continue to use this strategy even though it is inappropriate. This was demonstrated in the present study because the noise-induced bias continued even when the signal probabilities were returned to normal. Previous studies using higher noise intensities have shown that noise often increases the number of errors or gaps. The moderate intensity noise used in the present study did not have this effect.	

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1988	Smith, A.P. 1988. Acute effects of noise exposure: an experimental investigation of the effects of noise and task parameters on cognitive vigilance tasks. Int Arch Occup Environ Health 60:307-10.	Studies of sustained monitoring of sensory information have shown noise-induced impairments only when the level is above 95 dB. Recent results suggest that tasks involving the monitoring of cognitive information may be vulnerable at lower intensities. This last point was confirmed in the present study which used a dual task. Noise reduced the hitrate on a task involving detection of repeated numbers but had no effect on the average estimate of the relative probabilities of two classes of events. Noise did, however, increase the frequency of very inaccurate estimates. The noise effects were not altered by changes in the priority, difficulty or probability of the two tasks.	In vigilance studies under noise conditions, subjects have shown specific accuracy reductions for low-probability targets as well as an inability to adapt effectively to changes in target probability. This latter probably reflects a strategic shift by subjects to focus noise-limited attention on certain stimuli (e.g., high probability stimuli) at the expense of others.
1987	Smith, A.P. and C. Miles. 1987. The combined effects of occupational health hazard: an experimental investigation of the effects of noise, night work, and meals. Int Arch Occup Environ Health 59:83-89.	An experimental study of the effects of noise, nightwork and meals showed that these factors influenced different aspects of performance. Speed of performing a low memory load version of a visual search task was influenced by working at night but was unaffected by either noise or meals. A high memory load version of the search task was performed more slowly after consumption of a meal, both during the day and at night, but was not influenced by nightwork. Subjects working in noise produced more errors on the high memory load task than those working in quiet, but neither nightwork nor meals had significant effects on the number of errors. The only evidence of an interaction between factors was obtained in the high memory load search task, where noise reduced the size of the post-meal decline in speed. These results show that the effects of noise, nightwork and meals are largely independent, the exception being the beneficial effect of noise on post-lunch performance. They also demonstrate that the effects of all of these factors depend on the nature of the task being performed, and on whether speed or accuracy is the variable under consideration.	Effects of noise, nightwork and meals showed differences on aspects of performance (with only one minor indication of interaction). Also another demonstration that vigilance and other focused attention tasks appear especially vulnerable to ongoing noise that is unpredictable in period, frequency, and intensity.
2004	Smith, B. L., Byrne, K. G., Hennessy, S. M., and Goodall, N. J. 2004. An Investigation into the Impact of Rainfall of Freeway Traffic Flow. Paper presented at the 83rd Annual Meeting of the Transportation Research Board.	Transportation agencies are seeking to integrate weather data into traffic operations in order to improve system efficiency. In order to do so, it is essential that transportation professionals have a solid understanding of the impact of various weather conditions on traffic flow. The purpose of this research effort was to investigate the impact of rainfall, at varying levels of intensity, on freeway capacity and operating speeds. The findings of this study, derived from traffic and weather data collected in the Hampton Roads region of Virginia, add to the guidance currently available to professionals in the Highway Capacity Manual. The findings are summarized below. • Light rain (intensity of 0.01 - 0.25 inches/hour) decreases freeway capacity by 4-10% • Heavy rain (intensity of 0.25 inches/hour or greater) decreases freeway capacity by 2530%. • The presence of rain, regardless of intensity, results in approximately a 5.0-6.5% average decrease in operating speeds. These findings indicate that the impact of rain is more significant than currently reported in the Highway Capacity Manual, and therefore indicate the need to carefully examine freeway operations strategies during rainfall events	
2012	Smith, M. R., and C. Eastman. 2012. Shift Work: Health, Performance and Safety Problems, Traditional Countermeasures, and Innovative Management Strategies to Reduce Circadian Misalignment. Nature and Science of Sleep 4:111–132.	There are three mechanisms that may contribute to the health, performance, and safety problems associated with night-shift work: (1) circadian misalignment between the internal circadian clock and activities such as work, sleep, and eating, (2) chronic, partial sleep deprivation, and (3) melatonin suppression by light at night. The typical countermeasures, such as caffeine, naps, and melatonin (for its sleep-promoting effect), along with education about sleep and circadian rhythms, are the components of most fatigue risk-management plans. We contend that these, while better than nothing, are not enough because they do not address the underlying cause of the problems, which is circadian misalignment. We explain how to reset (phase-shift) the circadian clock to partially align with the night-work, day-sleep schedule, and thus reduce circadian misalignment while preserving sleep and functioning on days off. This involves controlling light and dark using outdoor light exposure, sunglasses, sleep in the dark, and a little bright light during night work. We present a diagram of a sleep-and-light schedule to reduce circadian misalignment in permanent night work, or a rotation between evenings and nights, and give practical advice on how to implement this type of plan.	This mechanism – light enhanced reduction in melatonin and subsequent increase in alertness -- may be partly responsible for the observed improvements in worker performance demonstrated with full-spectrum office lighting and with green- and blue-augmented lighting systems
1978	Smith, S. W., & Rea, M. S. (1978). Proofreading under different levels of illumination. Journal of the Illuminating Engineering Society, 88(18), 47-52.	The subjects' task in this experiment involved proofreading of paragraphs for misspelled words. Four young and four older subjects served in the experiment. It is concluded that age, print quality and illumination level significantly affect performance. Results indicate that performance improves with illumination but by varying degrees for different conditions. Further, increased illumination and good print quality are more important for older subjects than for young subjects.	
2010	Sörqvist P. 2010. The role of working memory capacity in auditory distraction: A review. Noise & Health 12(49):217-224.	The purpose of this paper was to review the current knowledge on individual differences in susceptibility to the effects of task-irrelevant sound on cognition. The literature indicates that at least two functionally different cognitive mechanisms underlie those differences; one is the efficiency by which people process the order between perceptually discrete sound events and the other is related to working memory capacity. The first mechanism seems to be involved only when disruption is a function of conflicting order processes, whereas the other mechanism is involved in a wider range of phenomena including those when attentional capture and conflicting semantic processes form the basis of disruption. Because of this, noise abatement interventions should first of all be directed towards people with low working memory capacity. Implications for theories of auditory distraction are discussed.	Individuals with particularly high working memory capacities appear to be less susceptible to auditory distraction by task-irrelevant speech noise than individuals with lower capacities

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2016	Sörqvist, P., Ö. Dahlström, T. Karlsson, and J. Rönnberg. 2016. Concentration: The Neural Underpinnings of How Cognitive Load Shields Against Distraction. Frontiers in Human Neuroscience 10:1-10. http://journal.frontiersin.org/article/10.3389/fnhum.2016.00221	Whether cognitive load—and other aspects of task difficulty—increases or decreases distractibility is subject of much debate in contemporary psychology. One camp argues that cognitive load usurps executive resources, which otherwise could be used for attentional control, and therefore cognitive load increases distraction. The other camp argues that cognitive load demands high levels of concentration (focal-task engagement), which suppresses peripheral processing and therefore decreases distraction. In this article, we employed a functional magnetic resonance imaging (fMRI) protocol to explore whether higher cognitive load in a visually-presented task suppresses task-irrelevant auditory processing in cortical and subcortical areas. The results show that selectively attending to an auditory stimulus facilitates its neural processing in the auditory cortex, and switching the locus-of-attention to the visual modality decreases the neural response in the auditory cortex. When the cognitive load of the task presented in the visual modality increases, the neural response to the auditory stimulus is further suppressed, along with increased activity in networks related to effortful attention. Taken together, the results suggest that higher cognitive load decreases peripheral processing of task-irrelevant information—which decreases distractibility—as a side effect of the increased activity in a focused-attention network.	Glare and/or insufficient lighting have the potential for adverse cross-modal effects, although there is no consensus about the specific mechanisms by which this occurs. When tasks are complex, degraded perceptual information quality may push the already taxed processing apparatus into an overloaded state in which the worker must apply all surplus resources to maintain good performance on the task. This can leave few or none to monitor other modalities, such as hearing.
1985	St. Germain, E.F. 1985. *The Effects of Environmental Factors on Worker Productivity in the Construction Industry*. University of Washington, Seattle, Washington.	Paper discusses the impacts (adverse and beneficial) environmental conditions have on human performance and productivity in the construction industry.	Potential application to flood mitigation construction related activities.
2015	St. John, M.F. 2015. "Developing a Set of Human Factors Barriers for Deepwater Drilling Risk Assessment." in Offshore Technology Conference. Houston, Texas	Author addresses shortcomings of human reliability estimates and suggests a human-factors centric approach for underlying systemic causes of incidents in oil and gas industry.	Potential application of human factors from high-hazard oil drilling environment to flood mitigation
2004	Staal, M.A. 2004. "Stress, Cognition, and Human Performance: A Literature Review and Conceptual Framework." NaSA technical memorandum 2128249.	The following literature review addresses the effects of various stressors on cognition. While attempting to be as inclusive as possible, the review focuses its examination on the relationships between cognitive appraisal, attention, memory, and stress as they relate to information processing and human performance. The review begins with an overview of constructs and theoretical perspectives followed by an examination of effects across attention, memory, perceptual-motor functions, judgment and decision making, putative stressors such as workload, thermals, noise, and fatigue and closes with a discussion of moderating variables and related topics. In summation of the review, a conceptual framework for cognitive process under stress has been assembled. As one might imagine, the research literature that addresses stress, theories governing its effects on human performance, and experimental evidence that supports these notions is large and diverse.	One of several authors that altogether have noted that while broadly enhancing gross flight-fight performances (e.g., strength), high arousal levels, such as those that would occur from exposure to adverse(if not risky) environments, interferes broadly with performance involving complex skills, fine muscle movements, coordination, steadiness, as well as general cognition.
2012	Staiger, H., Laschewski, G., Grätz, A. The perceived temperature – a versatile index for the assessment of the human thermal environment. Part A: scientific basics. Int J Biometeorol (2012) 56:165–176	Explains perceived temperature (PT) in detail the basic equations of the human heat budget and the coefficients of the parameterizations.	PT a steady-state model allows fast calculations. PT obtains a privileged status compared to other equivalent temps. Proved suitability for numerous applications at a wide variety of scales (micro to global) and is used in daily forecasts and in climatological studies.
2009	Stathopoulos, T. (2009). Wind and Comfort. In: 5th European & African conference on wind engineering: Florence Italy, July 19th-23rd 2009 Conference Proceedings. (pp. 1000-1016). Firenze University Press.	Wind plays always an important role in dealing with outdoor human comfort in an urban climate. Although various models of different complexity have been proposed to characterize the effect of wind on pedestrians in relation to their specific activities, it has been also recognized that human comfort in general may be affected by a wide range of additional parameters, including air temperature, relative humidity, solar radiation, air quality, clothing level, age, gender etc. Several criteria have been developed in the wind engineering community for evaluating only the wind-induced mechanical forces on the human body and the resulting pedestrian comfort and safety. It is also noteworthy that there are significant differences among the criteria used by various countries and institutions to establish threshold values for tolerable or unacceptable wind conditions even if a single parameter, such as the wind speed is used as criterion. These differences range from the speed averaging period (mean or gust) and its probability of exceedance (frequency of occurrence) to the methodology of evaluation of its magnitude (experimental or computational). The paper attempts to review some of the work carried out in this area and to address some of the most recent efforts to develop wind ordinances, as well as to incorporate additional parameters in order to specify the threshold values or comfort ranges for respective weather parameters. Ideally, for design purposes, an approach towards the establishment of an overall comfort index taking into account wind conditions and other microclimatic factors should be an ultimate objective.	
1989	Steele, T.P., D.A. Kobus, G.R. Banta, and C. Armstrong. 1989. Sleep Problems, Health Symptoms, and Tension/Anxiety and Fatigue During Wartime Cruising in a Moderately High Heat/Humidity Naval Environment. DTIC Document.	Study to look at the combined effects of multiple environmental stressors (e.g., extended operations and/or battle readiness conditions, imminent physical dangers, high heat/humidity) on the health and performance of personnel. Designed to continue the quantification of cognitive, behavioral, and physiological responses to sustained operations in a hostile theater of operations with the inclusion of high heat and humid conditions. The report presents findings from self-report sleep, health symptoms, and psychological measures. Subsequent reports will provide findings from cognitive testing and physiological measurements. Sample population is a cross-sectional sample of officers and enlisted personnel aboard 9 navy combatant ships.	Continuous exposure to humid, hot environments can result in sleep difficulties with associated adverse effects on physical, perceptual, and cognitive performance
2014	Stephens, J.M., C. Argus, and M.W. Driller. 2014. "The Relationship between Body Composition and Thermal Responses to Hot and Cold Water Immersion." *Journal of Human Performance in Extreme Environments* 11(2):	The study aimed to examine the influence of body fat percentage on thermal responses to water immersion at the two temperature extremes.	Water immersion combined with temperature; effects on human physiology

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1975	Stevens, SS (1975) Psychophysics. New York, NY: John Wiley & Sons. Taylor, L., Watkins, S. L., Marshall, H., Dascombe, B. J., & Foster, J. (2014). The Impact of Different Environmental Conditions on Cognitive Function: A Focused Review. Frontiers in physiology, 6, 372-372.	Psychophysics is a lively account by one of experimental psychology's seminal figures of his lifelong scientific quest for general laws governing human behavior. It is a landmark work that captures the fundamental themes of Stevens's experimental research and his vision of what psycho-physics and psychology are and can be. The context of this modern classic is detailed by Lawrence Marks's pungent and highly revealing introduction. The search for a general psychophysical law—a mathematical equation relating sensation to stimulus—pervades this work, first published in 1975. Stevens covers methods of measuring human psychophysical behavior: magnitude estimation, magnitude production, and cross-modality matching are used to examine sensory mechanisms, perceptual processes, and social consensus. The wisdom in this volume lies in its exposition of an approach that can apply generally to the study of human behavior.	
1981	Strandberg, L., and Lanshammar, H. 1981. The Dynamics of Slipping Accidents. Journal of Occupational Accidents 3(3):153-162.	Official statistics indicate that slipping is one of the most common causes of accidents. Falls contribute to about 40% of the 4000 fatal accidents that occur annually in Sweden. In fact, falls are more common than motor vehicles as a registered cause of accidental deaths. During 1975 occupational injuries caused approximately 3 million sickness-days and 26% of them were due to falling accidents. The actual involvement of skidding cannot be evaluated, because slip-ups have been registered only as a subgroup of "falls on the same level". However, skidding may initiate other types of accidents as well. This is supported by preliminary data from a new occupational injury information system. The computer based system allows selective retrievals. In one of the first outputs slip-ups are involved in at least 25 accidents out of 102 including "fall to a lower level" during house construction work. Thus it is urgently necessary to improve the slipping resistance of shoes, floors and walking surfaces. Development is guided by friction measurement with different kinds of apparatus. Unfortunately, many of these are based on an oversimplified theory of static friction, which seems to be quite irrelevant due to the viscoelastic properties of shoe soles and heels. However, even if the apparatus measures dynamic friction, tests must be performed with forces and motions closely resembling a real human skid. Otherwise, friction measurements and real slipping resistance will be poorly correlated.	Experimentally notes that as the heel begins to slip, whether the worker falls or not depends on that worker's ability to make recovery movements to regain balance, which may take up to 1/5th of a second for the average adult.
1970	Streimer, I., D.P.W. Turner, K. Volkmer, and D. Guerin. 1970. *Effects of the Underwater Environment Upon Work Efficiency of Divers.* MFI 70-117, Man Factors, Inc., San Diego, California.	Discussion of performance characteristics of divers during execution of manual work tasks.	Performance degradation related to submersion in water
2012	Suhir, E. 2012. "Human in the Loop: Predicted Likelihood of Vehicular Mission Success and Safety." *Journal of Aircraft* 49(1):29-36.	Discusses a model to quantify the likelihood of the failure of a human to perform his/her duties when operating a vehicle (aircraft or car) in harsh environment	Human performance related to operation of vehicles in harsh environment
1994	Sundstrom, E., J.P. Town, R.W. Rice, D.P. Osborn, and M. Brill. 1994. Office noise, satisfaction and performance. Environment and Behavior 26(2):195–222.	A field study assessed disturbance by office noise in relation to environmental satisfaction, job satisfaction, and jot performance ratings among 2,391 employees at 58 sites before and/or after office renovation. In all, 54% said they were bothered often by noise, especially by people talking and telephones ringing. Disturbance by noise correlated with dissatisfaction with the environment and job but not with self or supervisor-rated performance. Quasi-experimental analysis of groups reporting increased, decreased, or unchanged disturbance by noise revealed a drop in satisfaction concurrent with increasing noise. Disturbance by office noise may reflect a variety of environmental and job characteristics and may have a role in job satisfaction through both environmental satisfaction and job characteristics. Implications are discussed.	Speech noise, especially multi-speaker background conversations, is among the most disruptive type of noise for many cognitive tasks, having effects that other non- language types of noise do not.
2006	Sunwoo, Y.I, Chou, C., Takeshita, J., Murakami, M., and Tochihara, Y. 2006. Physiological and Subjective Responses to Low Relative Humidity in Young and Elderly Men. Journal of Physiological Anthropology 25(3):229-38.	In order to compare the physiological and the subjective responses to low relative humidity of elderly and young men, we measured saccharin clearance time (SCT), frequency of blinking, hydration state of the skin, transepidermal water loss (TEWL), sebum level recovery and skin temperatures as physiological responses. We asked subjects to evaluate thermal, dryness and comfort sensations as subjective responses using a rating scale. Eight non-smoking healthy male students (21.7+/-0.8 yr) and eight non-smoking healthy elderly men (71.1+/-4.1 yr) were selected. The pre-room conditions were maintained at an air temperature (Ta) of 25 degrees C and a relative humidity (RH) of 50%. The test-room conditions were adjusted to provide 25 degrees C Ta and RH levels of 10%, 30% and 50%. RH had no effect on the activity of the sebaceous gland or change of mean skin temperature. SCT of the elderly group under 10% RH was significantly longer than that of the young group. In particular, considering the SCT change, the nasal mucous membrane seems to be affected more in the elderly than in the young in low RH. Under 30% RH, the eyes and skin become dry, and under 10% RH the nasal mucous membrane becomes dry as well as the eyes and skin. These findings suggested that to avoid dryness of the eyes and skin, it is necessary to maintain greater than 30% RH, and to avoid dryness of the nasal mucous membrane, it is necessary to maintain greater than 10% RH. On the thermal sensation of the legs, at the lower humidity level, the elderly group felt cooler than the young group. On the dry sensation of the eyes and throat, the young group felt drier than the elderly group at the lower humidity levels. From the above results, the elderly group had difficulty in feeling dryness in the nasal mucous membrane despite being easily affected by low humidity. On the other hand, the young group felt the change of humidity sensitively despite not being severely affected by low humidity. Ocular mucosa and physiology of skin by dryness showed no difference by age. In the effect of longer exposure (180 min.) to low RH, only TEWL showed a slight decrease after 120 minutes in 30% RH, and all the measured results showed no noticeable differences compared with the result at 120 minutes.	When RH falls to 10 percent or below, mucous membranes in the nose and eyes become dry, increasing the occurrence of nosebleeds.
2011	Szalma, J.L., and P.A. Hancock. 2011. "Noise Effects on Human Performance: A Meta-Analytic Synthesis." *Psychological Bulletin* 137(4):682-707.	Authors present a quantitative evaluation of noise impact on human performance so that their harmful effects can be mitigated	Noise impacts on performance
2006	Szymber, R.J. 2006. *U.S. Army Tactical Weather Support Requirements for Weather and Environmental Data Elements and Meteorological Forecasts.* ARL-TR-3720, Army Research Laboratory, White Sands Missile Range, New Mexico.	This report addresses Army tactical requirements for weather and environmental data elements. Report identifies over 80 atmospheric (meteorological), state-of-the-ground (terrain), state-of-the-sea (oceanographic), and space weather data elements, including critical threshold values and impacts.	Info on impacts related to extreme environmental conditions

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2013	Szymber, R.J., Jameson, T.C. Quantitative Weather Impacts: An Integrated Weather Effects Decision Aid Impact Magnitude Gradation Scheme and Friendly Versus Threat Delta Advantage. White Sands Missile Range, NM 88002-5501. August 2013	Integrated Weather Effects Decision Aid (IWEDA) is outdated and needs updated.	Wants to change to a new system to enhance our troops and give them an advantage on the battlefield
2013	Szymber, R.J., Jameson, T., Knapp, D.I. 2006. A Parameter Weighting Scheme for an Automated Weather Effects Decision Aid. J. Operational Meteor., 1 (8), 84-92	Army analysts / weather officers use decision support tool called Integrated Weather Effects Decision Aid (IWEDA). IWEDA ingests weather forecast model grids, applies a rules/thresholds database to the grids, and produces color-coded overlays for terrain map backgrounds. Map overlays indicate the severity of weather impacts on Army weapon and support systems, and provide a valuable tool for mission commanders for battlefield operations. Useful but not updated since its inception, and its capabilities have fallen behind the numerical weather prediction models and computing platforms that are available today. Coarse color-coded maps are a simplistic green/amber/red scheme, all weather parameters are treated with equal weight, and there is no means of accounting how many model parameters are contributing to adverse weather effects.	Composite weather scoring system uses parameters with different weights; parameters contributing to adverse weather, and greater color granularity applied to the IWEDA map overlays. Higher color granularity and adjustable parameter weights are expected to afford much greater flexibility to commanders / intelligence analysts as weather effects are used in planning operations. Suitable for comparable operational civilian weather tech.
2016	Taber, M.J., G.L. Hartley, G.W. McGarr, D. Zaharieva, F.A. Basset, Z. Hynes, et al. 2016. "Cognitive Performance during a 24-Hour Cold Exposure Survival Simulation." *BioMedical Research International* 2016(8130731):1-11.	Survivor of a ship ground in polar regions may have to wait more than five days before being rescued. Therefore, the purpose of this study was to explore cognitive performance during prolonged cold exposure. Core temperature (c) and cognitive test battery (CTB) performance data were collected from eight participants during 24 hours of cold exposure (7.5 C ambient air temperature). Participants (recruited from those who have regular occupational exposure to cold) were instructed that they could freely engage in minimal exercise that was perceived to maintaining a tolerable level of thermal comfort. Despite the active engagement, test∘conditions were sufficient to significantly decrease c after exposure and to eliminate the typical 0.5–1.0 C circadian rise and drop in core temperature throughout a 24 h cycle. Results showed minimal changes in CTB performance regardless of exposure time. Based on the results, it is recommended that survivors who are waiting for rescue should be encouraged to engage in mild physical∘activity, which could have the benefit of maintaining metabolic heat production, improve motivation, and act as a distractor from cold discomfort. This recommendation should be taken into consideration during future research and when considering guidelines for mandatory survival equipment regarding cognitive performance.	Minimal changes in CTB test-battery performance were shown regardless of exposure time, when participants were encouraged to engage in mild exercise to maintain warmth. Based on the results, mild physical may be encouraged as means for distraction, if not maintaining warmth as well as maintaining performance capacity.
2013	Tajmir, P., Grierson L.E.M., Carnahan, H. Interactions between cold ambient temperature and older age on haptic acuity and manual performance. Canadian Journal on Aging / La Revue canadienne du vieillissement 32 (2) : 195–202 (2013)	Healthy younger and older persons performed a battery of haptic psychomotor tests at room (23° C) and cold (1° C) ambient temperatures.	Indicate older individuals don't perform as well as younger across the battery of tests, with cold temp further degrading their performance in dexterity tasks (Minn Manual Dexterity test placing: F [1, 16] =10.23, $p<.01$) and peak precision grip force generation (F [1, 16] = 18.97, $p<.01$). Cold weather may have an impact on occupations older persons are able to perform during the winter months.
2015	Tang, Y. Y., Hölzel, B. K., and Posner, M. I. (2015). The neuroscience of mindfulness meditation. Nature Reviews Neuroscience, 16(4), 213-225.	Research over the past two decades broadly supports the claim that mindfulness meditation — practiced widely for the reduction of stress and promotion of health — exerts beneficial effects on physical and mental health, and cognitive performance. Recent neuroimaging studies have begun to uncover the brain areas and networks that mediate these positive effects. However, the underlying neural mechanisms remain unclear, and it is apparent that more methodologically rigorous studies are required if we are to gain a full understanding of the neuronal and molecular bases of the changes in the brain that accompany mindfulness meditation.	
2016	Taylor, L., S. L. Watkins, H. Marshall, B.J. Dascombe, and J. Foster. 2016. "The Impact of Different Environmental Conditions on Cognitive Function: A Focused Review." *Frontiers of Physiology* 6(372):1-12.	The available evidence suggests that the effects of heat, hypoxia, and cold stress on cognitive function are both task and severity dependent. Complex tasks are particularly vulnerable to extreme heat stress, whereas both simple and complex task performance appear to be vulnerable at even at moderate altitudes. Cold stress also appears to negatively impact both simple and complex task performance, however, the research in this area is sparse in comparison to heat and hypoxia. In summary, this focused review provides updated knowledge regarding the effects of extreme environmental stressors on cognitive function and their biological underpinnings.	Discusses: (1) the current state of knowledge on the effects of heat, hypoxic and cold stress on cognitive function, (2) the potential mechanisms underpinning these alterations, and (3) plausible interventions that may maintain cognitive function upon exposure to each of these environmental stressors.
1958	Teichner W.H. 1958. "Reaction Time in the Cold." *Journal of Applied Psychology* 42:54-9.	"Visual RT's were elicited from 620 soldiers sorted into 14 different groups representing a variety of ambient temperatures, windspeeds and wind-chill 1. At low wind speed... low ambient temperature has no effect on RS [reciprocal of RT]. 2. At windspeeds of 10 mph and greater, low ambient temperature produces a significant decrease in RA. 3. Wind speed produces a significant decrease in RS. 4. Mild exercise produces a small recover in RS. 5. If men of low 'physiological cold tolerance' are removed from the more severe environmental conditions and if Ss wear protective clothing, RS is essentially a linear decreasing function of wind-chill."	Distraction theory, in cold context, holds that cold stress draws limited attentive resources away from physical and cognitive tasks, interfering with effective and efficient performance. (Otherwise discussed by Enander 1987).

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2009	Thomas, H., and R. Ellis. 2009. "Fundamental Principles of Weather Mitigation." Practice Periodical on Structural Design and Construction 14(1):29-35. http://dx.doi.org/10.1061/(ASCE)1084-0680(2009)14:1(29).	Contractors must often work in unfavorable weather. Two important questions arise. How much labor inefficiency will be incurred (which leads to the question of how much should the estimate be increased) and how can the negative impacts be mitigated? This paper addresses these two questions. The literature is reviewed and data from multiple projects are examined to estimate the average loss of efficiency resulting from very hot and very cold temperatures and from rain and snow. The average loss of efficiency estimates are used in a simple example to illustrate how to decide how much to increase the workhour estimate to account for adverse weather. Fundamental principles are stated so contractors can mitigate the effects of unfavorable weather conditions. It is postulated that if the principles are followed, labor inefficiencies resulting from weather-related disruptions are less likely to occur. - See more at: http://ascelibrary.org/doi/full/10.1061/(ASCE)1084-0680(2009)14%3A1(29)#sthash.BDIORhtK.dpuf	
1999	Thomas, H., D. Riley, and V. Sanvido. 1999. "Loss of Labor Productivity Due to Delivery Methods and Weather." Journal of Construction Engineering and Management 125(1):39-46.	This paper describes three structural steel erection projects that used different methods of delivering the structural steel members. Two projects scheduled daily deliveries. On one project, steel was erected directly from the truck. On the second project, steel was off-loaded, sorted, and then erected. On the third project, three bulk deliveries of steel were made. The steel was stored wherever space was available, and sorting was done as the steel was erected. The differences in labor productivity are quantified using the multiple regression technique. The analysis shows that the most efficient delivery method is to erect the steel directly from the truck. Double-handling, as was done on the second project, resulted in a loss of productivity of about 9%. Indiscriminate deliveries resulted in a loss of productivity of about 16%. The effects of weather are also quantified. Significant losses of productivity occurred because of snow (41%) and cold temperatures (32%). - See more at: http://ascelibrary.org/doi/abs/10.1061/%28ASCE%290733-9364%281999%29125%3A1%2839%29#sthash.nummBUCl.dpuf	
1989	Thomas, J.R., Ahlers, S.T., House, J.F., and Schrot, J. (1989). Repeated exposure to moderate cold impairs matching-to-sample performance. Aviat. Space Environ. Med. 60, 1063–1067.	To study effects of moderate cold (5 degrees C) on complex cognitive performance, subjects were exposed to cold while responding on a conditional discrimination task. The task required a correct choice of which of two simultaneously presented matrices matched a previously presented sample matrix. The effects of task performance in cold and ambient temperatures was examined on three repeated occasions, one pair of conditions per week. Responses accuracy was consistently impaired in each cold session. In addition, choice response latencies lengthened and sample response latencies decreased in all cold exposures. The data show that even moderate cold exposure that does not produce core hypothermia can impair performance of a complex cognitive task and that the magnitude of performance change is not attenuated by a brief series of cold exposures.	
1973	Thornton, W. A. 1973. Fluorescent lamps with high color-discrimination capability. Journal of the Illuminating Engineering Society 3:61–64.	Certain visual tasks require easy discrimination among colors differing only slightly. Much of human color experience involves this problem to a degree. Given an array of colored objects, discrimination among them depends on the illuminant; both its color and spectral power distribution are important. What appear to be optimum color and spectral power distribution have been found, and the capabilities of fluorescent lamps approaching this ideal are described and demonstrated.	Delineates that above minimum for cone-color vision, color discrimination relies primarily upon (1) the color output (or chromaticity) of the light illuminating the colored surface (apart from individual differences in color perception due to age or other factors)
2010	Tiller, D., Wang, L.M., Musser, A., Radik, M. 2010. - "Combined Effects of Noise and Temperature on Human Comfort and Performance"	Studies the effects of noise and temperature on human performance.	There were no statistically significant effects of thermal condition, RC level, or sound quality on performance of the typing or number-checking tasks.
1939	Tinker, M. A. (1939). The effect of illumination intensities upon speed of perception and upon fatigue in reading. The Journal of Educational Psychology, 8, 561-571.	Speed of reading was found to increase with increases in illumination intensity up to a point somewhere between 3.1 and 10.3 foot-candles when the eye is adapted for only 2 minutes to the brightness of light used; when the eye is adequately adapted (15 minutes adaptation time) the critical level for effective seeing is about 3 foot-candles or slightly below. Clearness of seeing was reduced by two hours of reading under intensities of less than 3.1 foot-candles.	
1964	Tulving, E., G. Mandler, and R. Baumal. 1964. Interaction of Two Sources of Information in Tachistoscopic Word Recognition. Can. J. Psychol. 18(1):62-71.	The combined effects of stimulus duration and linguistic context on the probability of correct recall of words were studied. Ss were asked to guess stimulus words projected for various lengths of time (0-140 msec.) in various lengths of context (0-8 words). It was observed that the number of correct responses increased with an increase of context and exposure time. In situations where the information given to Ss was issued both in the perceptive presentation of the stimulus and in the linguistic context, the probability of correct responses was higher than the hypothesis would predict, presuming that 2 information sources act in an independent and additive manner.	Demonstrates that word recognition tends to be increased under vibration when embedded in a sentence (aka, "sentence context effect."
1992	US Army, D.O.T. 1992. *Battlefield Weather Effects Field Manual.* FM 34-81-1, Washington, D.C.	This manual provides some of the more common critical weather (and environmental) effects data and applies that information to specific operations, systems, and personnel. Inclement weather degrades battlefield operations, affects weapons and other systems, and plays a major role in the effectiveness of troops in the field.	Performance degradation caused by weather Inclement weather degrades battlefield operations, affects weapons other systems, and plays a major role in the effectiveness of troops in the field.
2007	Van Hiel, A., and I. Mervielde. 2007. "The Search for Complex Problem-Solving Strategies in the Presence of Stressors." *Human Factors: The Journal of the Human Factors and Ergonomics Society* 49(6):1072-1082. http://hfs.sagepub.com/content/49/6/1072.abstract.	The present research tests the effects of time pressure and noise on cognitive abilities.	Cognitive effects related to exposure to environmental stressors

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1995	Vanggaard, L. 1995. *The Effects of Exhaustive Military Activities in Man. The Performance of Small Isolated Military Units in Extreme Environmental Conditions.* ADA389235, Royal Danish Navy, Danish Armed Forces Health Services, Gentofte, Denmark.	Discusses performance of military personnel in presence of extreme environmental conditions (cold).	Cold stress impact on performance
2006	Venetjoki, N., A. Kaarlela-Tuomaala, E. Keskinen, and V. Hongisto. 2006. "The Effect of Speech and Speech Intelligibility on Task Performance." *Ergonomics* 49(11):1068-1091. http://dx.doi.org/10.1080/00140130600679142.	The aim of this study was to find out what are the effects of three different sound environments on performance of cognitive tasks of varying complexity	Noise and communication
2004	Virués-Ortega, J., G. Buela-Casal, E. Garrido, and B. Alcázar. 2004. "Neuropsychological Functioning Associated with High-Altitude Exposure." *Neuropsychology Review* 14:197-224.	This article focuses on neuropsychological functioning at moderate, high, and extreme altitude. This article summarizes the available literature on respiratory, circulatory, and brain determinants on adaptation to hypoxia that are hypothesized to be responsible for neuropsychological impairment due to altitude. Effects on sleep are also described. At central level, periventricular focal damages (leuko-araiosis) and cortical atrophy have been observed. Frontal lobe and middle temporal lobe alterations are also presumed. A review is provided regarding the effects on psychomotor performance, perception, learning, memory, language, cognitive flexibility, and metamemory. Increase of reaction time and latency of P300 are observed. Reduced thresholds of tact, smell, pain, and taste, together with somesthetic illusions and visual hallucinations have been reported. Impairment in codification and short-term memory are especially noticeable above 6,000 m. Alterations in accuracy and motor speed are identified at lower altitudes. Deficits in verbal fluency, language production, cognitive fluency, and metamemory are also detected. The moderating effects of personality variables over the above-mentioned processes are discussed. Finally, methodological flaws found in the literature are detailed and some applied proposals are suggested.	Details neuropsychological effects of hypoxia from Altitude studies, which may be used to provide a model of heat induced hypoxia effects
2003	Ward, P., J.L. Szalma, and P.A. Hancock. 2003. "Stress, Human Information Processing, and Performance Mediators: Application of a Descriptive Framework to Current Modeling Tools." pp. 17. University of Central Florida, http://psychology.cos.ucf.edu/perl/wp-content/uploads/2013/01/Ward-Szalma-Hancock-2003-framework-for-stress-performance.doc	The effects of stress upon performance have typically been researched using either an input (e.g., environmental stressors), throughput (e.g., adaptive processes) or output (e.g., physiological response) approach rather than considering each as part of a single dynamic process. The extant research has also tended to focus upon the effects of a single environmental stressor on one specific cognitive process and has often failed to consider the multidimensionality of stress. To address these issues, Hancock and Warm (1989) outlined a dynamic model of stress and performance detailing an individual's psychological and physiological adaptability to stressful environments. The model predicts that psychological adaptability (e.g., attentional narrowing) is exhausted in a similar manner to the way in which stress degrades physiological response capacity (e.g., homeostatic regulation). Within this model, task demand is proposed to be one of the primary sources of stress. According to the model, the effect of stress upon task performance is intimately related to the nature of the task, type of stressor and moderators of the stress-performance relationship. However, without a comprehensive evaluation of the literature, prediction of how task performance will be debilitated or facilitated by stress, or whether stress effects can be alleviated remains to be fully answered. A three dimensional matrix is proposed to detail the effects of stress on information processing as well as moderators of the stress-performance relationship. The aim of this paper is to present a descriptive framework that will inform current modeling practice in a military context. The U.S. ARL-HRED presently employ a task network modeling architecture, IMPRINT, to predict soldier system performance under stress. Within IMPRINT, performance shaping functions and stress degradation algorithms are applied to modeled data to reflect individual differences in task performance under stressful conditions. Performance on military occupational specialty tasks is currently modeled under standardized conditions using the ACT-R cognitive architecture. Whilst IMPRINT has been successfully implemented, it is somewhat limited both by the availability of suitable stress degradation algorithms and the broad brush approach used to apply the same function/algorithm to all tasks grouped together by a taxonomic classification system. The matrix aims to provide resolution, at least in part, to a number of issues in this regard. Firstly, by clearly outlining the multitude of environmental, physical and task-related stressors within the matrix, and considering the transactional relationship between operator and task, a more complete understanding of stress effects on human performance can be delineated. Similarly, a comprehensive description and subsequent quantification of the effects of stressors on a range of information processing variables sub-serving, perception, cognition, and action will allow both theoretical and practical implementation issues related to current modeling approaches to be addressed. In addition, the inclusion of moderator variables within the matrix will provide an added dimension that will facilitate future modeling endeavors.	
1995	Warren W.H., and J.A. Saunders. 1995. Perceiving Heading in the Presence of Moving Objects. Perception 24(3):315–331.	In most models of heading from optic flow a rigid environment is assumed, yet humans often navigate in the presence of independently moving objects. Simple spatial pooling of the flow field would yield systematic heading errors. Alternatively, moving objects could be segmented on the basis of relative motion, dynamic occlusion, or inconsistency with the global flow, and heading determined from the background flow. Displays simulated observer translation toward a frontal random-dot plane, with a 10 deg square moving independently in depth. The path of motion of the object was varied to create a secondary focus of expansion (FOE') 6 deg to the right or left of the actual heading point (FOE), which could bias the perceived heading. There was no effect when the FOE was visible, but when the object moved in front of it, perceived heading was biased toward the FOE' by approximately 1.9 degrees with a transparent object, and approximately 3.4 degrees with an opaque object. The results indicate that scene segmentation does not occur prior to heading estimation, which is consistent with spatial pooling weighted near the FOE. A simple template model based on large-field, center-weighted expansion units accounts for the data. This may actually represent an adaptive solution for navigation with respect to obstacles on the path ahead.	Directional precipitation, especially snowfall, can produce this induced motion effect and systematic heading judgment errors in driving simulators

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2008	Warwick, W., R. Archer, A. Hamilton, M. Matessa, A. Santamaria, R.S. Chong, L. Allender, T. Kelley. 2008. "Integrating Architectures: Dovetailing Task Network and Cognitive Models." in 17th Conference on Behavior Representation in Modeling and Simulation, pp. 7. http://cc.ist.psu.edu/BRIMS/archives/2008/Papers/08-BRIMS-030.pdf.	This paper describes our efforts to develop the Human Behavior Architecture (HBA), an integration of task network and cognitive modeling tools. We begin by describing the two component modeling tools we have integrated: C3TRACE, a task network modeling tool and the ACT-R cognitive architecture. Next, we describe the current state of the integration, highlighting practical aspects. We then turn to a discussion of conceptual issues that have surfaced as we put integration into practice. Finally, we discuss the benefit we see in this integration.	
2013	Webster, G.D., D. Agdas, F.J. Masters, C.L. Cook, and A.N. Gesselman. 2013. "Prior Storm Experience Moderates Water Surge Perception and Risk." PloS one 8(5):e62477. http://journals.plos.org/plosone/article/asset?id=10.1371%2Fjournal.pone.0062477.PDF.	How do people perceive fast-moving water? How accurate are their perceptions? What makes some people more accurate than others? To answer these questions, we designed a within-person experiment that immersed people in various water depths and speeds, and asked them to estimate the speed of the moving water and how much personal risk they felt. Before the experiment, we asked them about prior experience with rip current and tropical cyclones (i.e., tropical storms with sustained winds ≥39 mph [63 km/h or 17.5 m/s]; hereafter referred to as "storms"). We made two predictions. First, we expected that the relationship between actual and perceived water speed would be more accurate (less overestimating) among people with more prior experience. Second, we expected that perception of water speed would at least partially mediate the direct relationship between actual water speed and risk, and that this direct relationship would be stronger among people with more storm experience (moderated mediation;	Showed that moving water can generate PORs and associated fear and anxiety in operators, especially when they do not have previous experience with the specific conditions.
1966	Weinstein, A., and R.S. Mackenzie. 1966. Manual performance and arousal. Perceptual Motor Skills. 22: 498.		
1982	Weinstein, N. D. 1982. Community noise problems: Evidence against adaptation. Journal of Environmental Psychology 2(2): 87-97.	It is commonly believed that people adapt rather easily to noise. This article reviews the available research, finding little evidence that any adaptation occurs in community settings. Much of this research, however, is open to alternative interpretations. The present study, examining reactions to traffic noise from the opening of a major new highway, was designed to remedy many of the problems with previous research. The investigation incorporated both a repeated measures design (the same respondents were interviewed 4 and 16 months after the highway opening) and an independent groups design (separate groups were interviewed either 4 or 16 months after opening). In addition, a pre-opening interview was carried out with the repeated measures panel. There was no evidence of appreciable adaptation in self-reported noise effects, annoyance, or tendency to focus attention on the noise. Instead respondents became more pessimistic about their ability to adapt to noise as time went by.	Both 1) demonstrates that people -- despite common belief do not easily adapt to noise and 2) Offers number of noise mitigation approaches
1997	Weller, A.S., C.E. Millard, M.A. Stroud, P.L. Greenhaff, and I.A. Macdonald. 1997. "Physiological Responses to Cold Stress During Prolonged Intermittent Low- and High-Intensity Walking." The American journal of physiology 272(6):2025-2033.	In a previous study [Am. J. Physiol. 272 (Regulatory Integrative Comp. Physiol. 41): R226-R233, 1997], the physiological responses to 240 min of intermittent low-intensity walking exercise in a cold (+5 degrees C), wet, and windy environment (Cold) may have been influenced by a 120-min preceding phase of intermittent higher-intensity exercise. Furthermore, the physiological responses observed during this latter phase may have been different if it had been more prolonged. To address these questions, active men attempted a 360-min intermittent (15 min of rest, 45 min of exercise) exercise protocol in Cold and a thermoneutral environment (+15 degrees C, Neutral) at a low (0% grade, 5 km/h; Low; n = 14) and a higher (10% grade, 6 km/h; High; n = 10) intensity. During Low, rectal temperature was lower in Cold than in Neutral, whereas O2 consumption, carbohydrate oxidation, plasma norepinephrine and epinephrine, and blood lactate were higher. During High, Cold had a similar but less marked influence on the thermoregulatory responses to exercise than during Low. In conclusion, the physiological responses to Low are similarly influenced by Cold whether or not they are preceded by High. Furthermore, during intermittent exercise up to an intensity of approximately 60% of peak O2 consumption, a cold, wet, and windy environment will influence the physiological responses to exercise and potentially impair performance.	
1998	Weller, A.S., Millard, C.E., Greenha, P.L., Macdonald, I.A. 1998. The influence of cold stress and a 36- h fast on the physiological responses to prolonged intermittent walking in man. Eur J Appl Physiol (1998) 77: 217-223	Compared VO2, rectal temp, resp exchange ratio, mean skin temp, and heart rate with fasting vs fed in a cold stressed environment.	Found that fasting vs fed didn't impair temperature regulation.
1996	Wertheim, A.H. 1996. *Human Performance in a Moving Environment*. TM-96-A063, TNO Human Factors Research Institute, Soesterberg, The Netherlands.	The paper provides a review of research concerning how and why working in a moving environment may affect performance.	Performance degradation associated with movement (as on a boat, or vehicle), balance problems, physical fatigue
2013	Wessel, J. R., & Aron, A. R. (2013). Unexpected events induce motor slowing via a brain mechanism for action-stopping with global suppressive effects. Journal of Neuroscience, 33(47), 18481-18491.	When an unexpected event occurs in everyday life (e.g., a car honking), one experiences a slowing down of ongoing action (e.g., of walking into the street). Motor slowing following unexpected events is a ubiquitous phenomenon, both in laboratory experiments as well as such everyday situations, yet the underlying mechanism is unknown. We hypothesized that unexpected events recruit the same inhibition network in the brain as does complete cancellation of an action (i.e., action-stopping). Using electroencephalography and independent component analysis in humans, we show that a brain signature of successful outright action-stopping also exhibits activity following unexpected events, and more so in blocks with greater motor slowing. Further, using transcranial magnetic stimulation to measure corticospinal excitability, we show that an unexpected event has a global motor suppressive effect, just like outright action-stopping. Thus, unexpected events recruit a common mechanism with outright action-stopping, moreover with global suppressive effects. These findings imply that we can now leverage the considerable extant knowledge of the neural architecture and functional properties of the stopping system to better understand the processing of unexpected events, including perhaps how they induce distraction via global suppression.	
1945	Weston, H. C. (1945). The relation between illumination and visual efficiency: The effect of brightness contrast. Industrial Health Research Report No. 87. London, U.K.: Great Britain Medical Research Council.	This is a report of the Industrial Health Research Board of the British Medical Research Council dealing with the effect of characteristics such as size, contrast and brightness on the facility with which objects can be seen. It is highly technical and presents most interesting experimental work and conclusions that are of interest mainly to psychologists, physicists and physiologists. Clinical applications are not included in this brochure.	Early support for 50-200 lux range for most tasks (but see Figure 6.6-7).

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1953	Weston, H. C. (1953). Visual fatigue with special reference to lighting. Transactions of the Illuminating Engineering Society 17, 39-66.	Visual fatigue" is often mentioned in discussions on the effects of different systems of lighting. Because the state so-named is not well understood, the nature and extent of the activities involved in seeing are examined to find a basis for it. Retinal fatigue—if it occurs at all—gives no feeling of "visual fatigue." But vision is essentially a motor as well as a sensory process. Numerous muscles are necessarily at work for seeing; the action of others—of the face, head and neck—is common and helpful, and the whole voluntary neuromuscular system of the body participates in acts of the most intent vision. From excessive muscular—though not exclusively oculo-muscular—exertion and from "mental exertion" comes so-called "visual fatigue." Such exertion may be due to unsuitable lighting, to "unphysiological" visual tasks or to ocular defects. Some relevant visual posture and time studies are described, and also, a study of facial muscular reactions to glare. Boredom and sleepiness due to lighting are distinguished from fatigue, and a definition is offered of "visual fatigue" in terms of the common meaning of "fatigue."	Continuing early support for 50-200 lux range for most tasks (but see Figure 6.6-7).
1970	Wheeler, D.D. 1970. Processes in word recognition. Cognitive Psychology, 1:59-85.	Five hypotheses were proposed and tested to account for Reicher's (1968) finding that recognition of letters is more accurate in the context of a meaningful word than alone, even with redundancy controlled by a forced-choice design. All five hypotheses were rejected on the basis of the experimental results. Performance on the forced-choice letter detection task averaged 10% better when the stimuli were four-letter English words than when the stimuli were single letters appearing alone in the visual field. Three classes of models were proposed to account for the experimental results. All three are based on analysis of the task in terms of the extraction of features from the stimuli.	
1987	White, M. K. and T.K. Hodous. 1987. Reduced work tolerance associated with wearing protective clothing and respirators. American Industrial Hygiene Association Journal, 48(4): 304-310.	Clothing ensemble (through the extent to which it adds weight and alters heat transfer) and work level (through metabolic heat production) were evaluated as factors of potential significance in determining cardiorespiratory and thermal stress in the workplace. The subjects of this investigation were nine male volunteers between the ages of 21 and 34 years, all with prior use and knowledge of handling of respirators and protective clothing. Two workloads performed on a treadmill and representing 30 and 60 percent of each subject's aerobic capacity were chosen for submaximal tests. During these tests subjects performed while attired in one of four increasingly protective clothing ensembles: (a) light work clothing with a low resistance mask; (b) light work clothing with a self-contained breathing apparatus; (c) firefighter's gear with a self-contained breathing apparatus; or (d) chemical protective ensemble with self-contained breathing apparatus. Significant decreases in workload tolerance to 22.2 percent, 84.4 percent and 56.3 percent for low intensity exercise and 74.4 percent, 95.6 percent and 85.6 percent for high intensity exercise for ensembles (b), (c) and (d) as compared to ensemble (a) were observed. These data and other reported physiological measurements indicated that during high intensity exercise, protective clothing and respirators severely limited the subjects' ability to perform work. Responses observed in this study suggested that heart rate was a more reliable indicator of overall work tolerance in the field and a more reliable gauge of worker capacity than measurements of skin or rectal temperatures.	
2016	Wickens, C, J. Hollands, S. Banbury, and R. Parasuraman. 2016. Engineering Psychology and Human Performance. 2016. Routledge, New York, NY.	Forming connections between human performance and design Engineering Psychology and Human Performance, 4e examines human-machine interaction. The book is organized directly from the psychological perspective of human information processing. The chapters generally correspond to the flow of information as it is processed by a human being--from the senses, through the brain, to action--rather than from the perspective of system components or engineering design concepts. This book is ideal for a psychology student, engineering student, or actual practitioner in engineering psychology, human performance, and human factors Learning Goals Upon completing this book, readers should be able to: * Identify how human ability contributes to the design of technology. * Understand the connections within human information processing and human performance. * Challenge the way they think about technology's influence on human performance. * show how theoretical advances have been, or might be, applied to improving human-machine interaction	
2010	Wilkins, A. and B. Lehman. 2010. A Review of the Literature on Light Flicker: Ergonomics, Biological Attributes, Potential Health Effects, and Methods in Which Some LED Lighting May Introduce Flicker. IEEE Standard P1789. http://grouper.ieee.org/groups/1789/FlickerTR1_2_26_10.pdf	This report is intended to be a draft sub-section of the final report from the IEEE Standards Working Group, IEEEPAR1789 "Recommending practices for modulating current in High Brightness LEDs for mitigating health risks to viewers." The final recommended practice report aims to be completed and be approved at the end of 2010. This document intends to explain some potential health consequences of flicker in LED lighting and demonstrate that existing technologies for LED driving may flicker at frequencies that may have health effects.	Summary of Flicker effects: 1) can affect perception, particularly when combined with movement of the light source, 2) flicker at frequencies >1,000 Hz can produce illness similar to motion sickness, featuring symptoms that include headaches, fatigue, and nausea and 3) long wavelength (i.e., red) LED displays may be perceived as a series of dots under vibration if their refresh rates are relatively slow (e.g., 60 Hz).
1982	Wilkins, P. A. and W.I. Acton. 1982. Noise and accidents—a review. Annals of Occupational Hygiene 25(3):249-260.	This review examines the evidence for a possible relationship between accidents and noise in industry. It has often been asserted that noise can be the cause of accidents; however, only five studies have attempted to assess the extent of this problem. These studies have indicated that high noise levels may be associated with higher accident rates and therefore provide suggestive but not conclusive evidence that noise is a contributory factor in the causation of accidents. The possible mechanisms of such an effect include the role of noise in causing a lack of attention and the masking of important auditory signals such as warning shouts, sirens and machinery sounds which indicate impending danger. In addition, the effects of a noise-induced hearing loss and the need to wear personal hearing protection to counter the noise could contribute indirectly to accidents by interfering with auditory communications. It is concluded that the possible link between noise and industrial accidents further emphasizes the need for reducing noise in industry and that this should be achieved wherever possible by means of noise control.	

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1964	Wilkinson, R. T., Fox, R. H., Goldsmith, R., Hampton, F. G., & Lewis, H. E. (1964). Psychological and physiological responses to raised body temperature. Journal of Applied Physiology, 1, 287-291.	The performance of 12 male volunteers in an adding test and in a test requiring prolonged vigilance was measured at normal body temperature and while temperature was maintained at 37.3, 37.9, and 38.5 C. Each subject was measured at each level of body temperature on four occasions. Both the extent and the direction of the effect on performance varied with 1) the task being carried out, and 2) the degree of temperature elevation. Compared with performance at normal temperatures, the ability to add was impaired and vigilance was improved at 38.5 C. At 37.3 C, on the other hand, smaller changes reflected in general an improvement in adding and an impairment of vigilance. As a result of the repeated sessions of controlled hyperthermia, the subjects became heat acclimatized but there was no corresponding improvement in performance at raised body temperature, indicating the absence of short-term adaptation of the central nervous system functions tested to repeated elevations of body temperature.	
1975	Williamson, Roger L., and Charles M. Kindick. 1975. *Human Performance in the Tropics II: A Pilot Study on Load-Carrying Test Methodology.* No. USATTC-7511001. ARMY TROPIC TEST CENTER APO MIAMI 34004, 1975. http://www.dtic.mil/docs/citations/ADA025460	A Pilot Study on Load Carrying Test Methodology was conducted in 1973 by the US Army Tropic Test Center in the Panama Canal Zone to determine sample sizes needed in future tests requiring a jungle patrol, and to determine the utility of two human performance decrement measurements. Combat troops carried loads from 25 to 55 pounds over a 4-kilometer jungle portability course simulating combat activity. In general, time to perform activities tended to increase with increased load. Sample sizes of 12 groups of three individuals, or 16 groups of two individuals, were determined as sufficient for future normative data collection studies within the 25- to 55-pound load range. A land navigation test demonstrated potential usefulness as a performance decrement measure, if revised to eliminate measurement problems encountered in the pilot test. An arm-hand steadiness test provided procedural guidelines for establishing psychomotor tests as a part of the portability course.	
1974	Williamson, Roger L., and Charles M. Kindick. 1974. *Human Performance in the Tropics I: Man-Packing A Typical Load over a Standard Jungle Course in the Wet and Dry Seasons.* No. USATTC-7409002. ARMY TROPIC TEST CENTER APO MIAMI 34004. http://www.dtic.mil/docs/citations/ADA017274	In 1972, the US Army Tropic Test Center conducted studies of the performance of combat soldiers in the natural jungle of the Panama Canal Zone. A standard 4-kilometer course was established in rugged juggle terrain and vegetation to yield group and individual scores on timed performance events and physiological factors. This study compare-s seasonal toot mobility by testing, soldiers in the dry and wet seasons. A total of 100 soldiers traversed the course carrying a standard 25-pound load. Measurements were made of a forced march, an uphill run, double timing, normal walking, total course time, weight loss, and water consumption. Results showed a 1.2 to 1 ratio of wet season to dry season march rates for the forced march uphill run, normal walk, and total course timed events. The double-time march rate and the physiological measures showed no seasonal differences. The main reason for lower foot mobility in the wet season was the higher percent soil moisture in the wet season (63 percent by weight as compared with 26 percent by weight for the dry season).	Early report that it took 20 percent longer to complete a walking task during the tropical "wet season" with 85 RH) than it took during the "dry season" with similar temperature but less RH. Strongly supported by more recent research (e.g., Richmond et al. 2015, and Chang et al. 2016).
2007	Wilson, D. K., R.J. Greenfield, and M.J. White. 2007. Spatial structure of low-frequency wind noise. J. Acoustical Society of America, 122(6), EL223-EL228.	The distinguishing spatial properties of low-frequency microphone wind noise (turbulent pressure disturbances) are examined with a planar, 49-element array. Individual, propagating transient pressure disturbances are imaged by wavelet processing to the array data. Within a given frequency range, the wind disturbances are much smaller and less spatially coherent than sound waves. Conventional array processing techniques are particularly sensitive to wind noise when sensor separations are small compared to the acoustic wavelengths of interest.	Acoustical physics investigation describing how wind affects the acoustical environment and associated communication, both verbal and microphone.
1974	Wilson, R. V. 1974. Display collimation under whole-body vibration. Human Factors: The Journal of the Human Factors and Ergonomics Society, 16(2), 186-195.	The presence and absence of a collimating lens over a display face was evaluated at 2, 4, 6, 8, and 10 Hz whole-body vibration with a compensatory tracking task. The collimating lens significantly improved tracking performance at 4 and 6 Hz. The results are discussed in terms of body resonance phenomena and compensatory eye movements.	Measures mitigation of vibration effects
1976	Wohlwill, J.P., J.L. Naser, D.M. DeJoy, and H. H. Foruzan. 1976. Behavioral effects of a noisy environment: Task involvement versus passive exposure. Journal of Applied Psychology, 61: 67.	Compared the effects of noise under active task involvement as opposed to passive exposure, using 80 undergraduate Ss who were assigned to 1 of 4 conditions representing 2 * 2 combinations of task vs no task and noise vs quiet. Performance on a dial-monitoring task was unaffected by noise. Ratings of interest and tenseness were significantly higher under the task condition; tenseness was also higher under noise. On a posttest of resistance to frustration, both noise groups, regardless of task condition, showed a smaller degree of persistence on insoluble puzzles than the no-noise groups. Results suggest that aftereffects of noise are not dependent on the power of noise to disrupt task performance.	Noise stress effects -- in keeping with noise-arousal theory -- are more pronounced when noise is worker's control (vs when workers have some control over the noise).
2004	Wojciechowski, J.Q. 2004. Validation of Improved Research Integration Tool (Imprint) Driving Model for Workload Analysis. DTIC Document.	The Human Research and Engineering Directorate of the U.S. Army Research Laboratory developed a model of the tasks and workload associated with driving a ground vehicle. The human performance modeling tool, Improved Performance Research Integration Tool (IMPRINT), was used to simulate the driving tasks. Perception, cognition, and motor control were represented in the IMPRINT driving model. Human processing, attention, and response were simulated as concurrent discrete events. Subsequently, the driving model was incorporated into other IMPRINT models used to investigate crew size and function allocation in Future Combat Systems (FCS) conceptual ground vehicles. Driving is a primary crew function in FCS ground vehicles. The results of this study indicated that a dedicated driver was recommended in combat vehicles. In all configurations tested, the driver was consistently the crew member with the highest workload. As expected, results of simulation runs were consistent with research on driving and distraction. Structural and output validation of the model was completed through literature review. Driving by itself is a high mental workload function. The human processing capacity is fully engaged in tasks when one is driving, with the primary load being in perception and cognition. Literature shows that performance will start to degrade if additional tasks are attempted during driving, especially if the tasks are highly perceptual or cognitive. This model provides a reasonably simple way to represent the driving function and can be used for investigating any system where driving is important. For FCS, this will include direct driving and teleoperations. Several additional validation studies are planned.	
2007	Wojciechowski, J.Q. 2007. Development of a User-Defined Stressor in the Improved Performance Research Integration Tool (Imprint) for Conducting Tasks in a Moving Vehicle. DTIC Document.	Human performance modeling tools are used to predict the effect of human performance on the system. The U.S. Army Research Laboratory developed a human performance modeling tool, the Improved Performance Research Integration Tool (IMPRINT), which allows an analyst to investigate the effect of subjecting operators to environmental stressors on mission performance. The latest version of IMPRINT has the capability to create user-defined stressors to study the effect of stress on human performance and therefore system performance. This study used data that predict the effect on task time and performance based on task characteristics when Soldiers are riding in a moving vehicle to create a user-defined stressor in IMPRINT. A case study was completed on a simple model of command and control tasks. The user-defined stressor was applied to show the effect of completing these tasks on task time and accuracy after participants were in a moving vehicle for 0, 1, 2 3, 4, and 5 hours. The data from the study indicate that tasks are affected differently, but most data show an increase in time complete and a decrease in the accuracy of the operator. This study shows the effect of operating in a moving vehicle. These data are useful not only to system design but also to the development of tactics and procedures.	

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
1982	Woldstad, J.C., A.C. Bittner, and J.C. Guignard. 1982. A methodological investigation of subject input/output error during vibration. Proceedings of the 26th Annual Meeting of the Human Factors Society (pp. 533-537). Santa Monica, CA: Human Factors Society.	An auditory-input/keypad-output system was evaluated for use as a performance test system that would be independent of artefactual vibrational decrement. Six young Navy volunteers were administered a non-cognitive Auditory Response Task Before, During, and After whole-body sinusoidal vibration. Two were tested at each of three vibration conditions (8 Hz/0.21 gzrms, 16 Hz/0.43 gzrms, and 32 Hz/0.85 gzrms). Results showed no direct decrement due to vibration, but a moderately significant subjects-within-conditions by frequency interaction. This interaction, paired with subjective measures taken during experimentation, pointed to a deficit in the keypad output system. It was concluded that the system was not satisfactory for future experimentation and recommended that a modified input system be developed. It is noted that purely cognitive effects of vibration have not been identified in the body of previous research.	Classical demonstration that cognitive -- and other- task performances -- both 1) degrade in part due to vibration's mechanical interference with responding, and 2) this may be largely addressed by improvements to the response interface.
2007	Wolkoff, P., and S.K. Kjærgaard. 2007. The Dichotomy of Relative Humidity on Indoor Air Quality. Environment International 33(6):850-857.	Dry and irritated mucous membranes of the eyes and airways are common symptoms reported in office-like environments. Earlier studies suggested that indoor pollutants were responsible. We have re-evaluated, by review of the literature, how low relative humidity (RH) may influence the immediately perceived indoor air quality (IAQ), including odor, and cause irritation symptoms (i.e. longer-term perceived IAQ). "Relative humidity" were searched in major databases, and combined with: air quality, cabin air, dry eyes, formaldehyde, inflammation, mucous membranes, offices, ozone, pungency, sensory irritation, particles, precorneal tear film, sick building syndrome, stuffy air, and VOCs. The impact of RH on the immediately and longer-term perceived IAQ by VOCs, ozone, and particles is complex, because both the thermodynamic condition and the emission characteristics of building materials are influenced. Epidemiological, clinical, and human exposure studies indicate that low RH plays a role in the increase of reporting eye irritation symptoms and alteration of the precorneal tear film. These effects may be exacerbated during visual display unit work. The recommendation that IAQ should be "dry and cool" may be useful for evaluation of the immediately perceived IAQ in material emission testing, but should be considered cautiously about the development of irritation symptoms in eyes and upper airways during a workday. Studies indicate that RH about 40% is better for the eyes and upper airways than levels below 30%. The optimal RH may differ for the eyes and the airways regarding desiccation of the mucous membranes.	Report Low RH (<30 percent) has been associated with increased eye irritation, which may negatively affect work involving visual displays
2014	Wong, D.P., Chung, J.W., Chan, A.P., Wong, F.K., Wen, Y. Compaing the physiological and perceptual responses of construction workers (bar benders and bar fixers) in a hot environment. Applied Ergonomics 45 (2014) 1705-1711.	Synchronized physiological, perceptual, and environmental parameters were measured from construction rebar workers. The average duration of the 39 field measurements was 151.1 ± 22.4 min under hot environment (WBGT ¼ 31.4 ± 2.2 C), during which physiological, perceptual and environmental parameters were synchronized. Energy expenditure of overall rebar work, bar bending, and bar fixing were 2.57, 2.26 and 2.67 Kcal/min (179, 158 and 186 W).	Bar fixing had significantly higher physiological responses in heart rate (113.6 vs. 102.3 /min, $p<0.05$), oxygen consumption (9.53 vs. 7.14 ml/min/kg, $p<0.05$), and energy expenditure (2.67 vs. 2.26 Kcal/min, $p<0.05$) (186 vs. 158 W, $p<0.05$) compared to bar bending. Perceptual response was higher in bar fixing but not statistically significant.
1976	Wood, C.C., and R. Jennings. 1976. Speed-Accuracy Tradeoff Functions in Choice Reaction Time: Experimental Designs and Computational Procedures. Perception & Psychophysics 19 (1): 92-102.	The existence of tradeoffs between speed and accuracy is an important interpretative problem in choice reaction time (RT) experiments. A recently suggested solution to this problem is the use of complete speed-accuracy tradeoff functions as the primary dependent variable in choice RT, experiments instead of a single mean RT and error rate. This paper reviews and compares existing procedures for generating empirical speed-accuracy tradeoff, functions for use as dependent variables in choice RT experiments. Two major types of tradeoff function are identified, and their experimental designs and computational procedures are discussed and evaluated. Systematic disparities are demonstrated between the two tradeoff functions in both empirical and computer-simulated data. Although all existing procedures for generating speed-accuracy tradeoff functions involve empirically untested assumptions, one procedure requires less stringent assumptions and is less sensitive to sources of experimental and statistical error. This procedure involves plotting accuracy against RT over a set of experimental conditions in which subjects' criteria for speed vs. accuracy are systematically varied.	Classical consideration of the speed accuracy tradeoff
2007	Wright, N.L., and J.A. Plaga. 2007. Assessment of Human Performance in a Simulated Rotorcraft Downwash Environment. DTIC Document.	Operational Requirements Document (ORD) CAF 315-97-B calls for the development of a Personnel Recovery Vehicle (PRV) to be used during Combat Search and Rescue missions undertaken by the Special Operations Command. Tests were conducted in the Aerospace Vehicle Survivability Facility of the 46th Operation's Group's Munitions Test Division (46 OGM), WPAFB to determine the horizontal and vertical airflow velocity limits in which personnel can perform necessary tasks. Horizontal test profiles included subjects walking into airflow wearing representative gear and carrying a Stokes litter with a patient. Vertical tests included descending a fast rope, climbing a ladder, and hoisting a litter into the airflow. Data analysis resulted in definition of horizontal airflow velocity limits. Vertical airflow limits were not defined due to poor experimental flow conditions. Horizontal flow is the limiting factor operationally as it is much stronger than vertical flow.	
1996	Wyon DP, Wyon I, Norin F. Effects of moderate heat stress on driver vigilance in a moving vehicle. Ergonomics. 39(1):61-75.	A total of 83 drivers, 51 males and 32 females, aged 25-65, were recruited to drive an apparently unmodified passenger car for 1 h over at least four laps of a predetermined route on public roads, which included seven sets of traffic lights and sections limited to 50, 70, 90 and 110 km/h. They were randomly assigned to one of two thermal conditions (21 or 27 degrees C), and drove only during the hours of daylight. A computer initiated unprepared signals to which drivers would normally be alert. Drivers responded by pressing a foot-switch and reporting verbally. Signals were selected at random from 21 possible signals, and were presented for up to 3 min, with a random delay of 30-180 s after each response or failure to respond. The negative effect of heat stress on vigilance was statistically significant. At 27 degrees C, the overall proportion of missed signals was 50% higher and response times were 22% longer than they were at 21 degrees C. These effects of heat were significant and proportionally greater in the second half-hour, for subjects < 40 years and for speeds below 60 km/h (i.e. in city traffic). The latter finding suggests that heat may have increased arousal, and there was some indication of a redistribution of attention away from the most peripheral signals at the higher temperature. Overt driving errors were observed significantly more often at 27 degrees C than at 21 degrees C for women only.	Heat effects also appear for tasks requiring attention and executive control under more natural conditions. In this case, simulator studies of driving have shown an increase in both missed signals.

Study Year	Citation	Brief Summary or Abstract	Implications to Env. Conditions Study
2011	Wyss, T., and U. Mäder. 2011. "Energy Expenditure Estimation During Daily Military Routine with Body-Fixed Sensors." Military medicine 176(5):494-499. https://www.researchgate.net/profile/Thomas_Wyss2/publication/51185501_Energy_expenditure_estimation_during_daily_military_routine_with_body-fixed_sensors/links/5459e0380cf2cf516483ed09.pdf	The purpose of this study was to develop and validate an algorithm for estimating energy expenditure during the daily military routine on the basis of data collected using body-fixed sensors. First, 8 volunteers completed isolated physical activities according to an established protocol, and the resulting data were used to develop activity-class-specific multiple linear regressions for physical activity energy expenditure on the basis of hip acceleration, heart rate, and body mass as independent variables. Second, the validity of these linear regressions was tested during the daily military routine using indirect calorimetry (n = 12). Volunteers' mean estimated energy expenditure did not significantly differ from the energy expenditure measured with indirect calorimetry (p = 0.898, 95% confidence interval = -1.97 to 1.75 kJ/min). We conclude that the developed activity-class-specific multiple linear regressions applied to the acceleration and heart rate data allow estimation of energy expenditure in 1-minute intervals during daily military routine, with accuracy equal to indirect calorimetry.	
2014	Xia, J.Q., R.A. Falconer, Y.J. Wang, and X.W. Xiao. 2014. "New Criterion for the Stability of a Human Body in Floodwaters." *Journal of Hydraulic Research* 52(1):93-104.	Authors propose a criterion for the stability of a human body in floodwaters in the form of an incipient velocity. Two formulae for the incipient velocity of a human body for sliding and toppling instability were derived	Criteria for human stability floodwaters.
1993	Yantis, S. 1993. Stimulus-driven Attention Capture. Current Directions in Psychological Science 2:156–161.	Jonides and Yantis (1988) found that abrupt-onset singletons capture attention in visual search when onset is orthogonal to the target's defining and reported attributes and that color and brightness singletons do not. They concluded that abrupt onset may be unique in capturing visual attention. Folk, Remington, and Johnston (1992) challenge this conclusion and argue that (a) the occurrence of attentional capture is contingent on the adoption of an appropriate attentional control setting by the observer and (b) properties other than onset (in particular, color) can capture attention involuntarily. In this article, each of these claims is critically evaluated, and it is argued that the results reported by Folk et al., though important, do not definitively corroborate either one. The available evidence concerning stimulus-driven attentional capture is summarized, and 3 empirical generalizations that characterize the evidence are advanced.	Classical report that new objects attract attention, suggesting that precipitation-shortened line-of-sight and greater effort required to see, identify, and geophysically locate features of the environment may increase drivers' difficulty attending to signage and lane maintenance
2014	Yokota, M., L.G. Berglund, and X. Xu. 2014. "Thermoregulatory Modeling Use and Application in the Military Workforce." Applied Ergonomics 45(3):663-670. http://www.sciencedirect.com/science/article/pii/S0003687013001877.	Thermoregulatory models have been used in the military to quantify probabilities of individuals' thermal-related illness/injury. The uses of the models have diversified over the past decade. This paper revisits an overall view of selected thermoregulatory models used in the U.S. military and provides examples of actual practical military applications: A) the latest military vehicle designed with armor and blast/bulletproof windows was assessed to predict crews' thermal strains levels inside vehicles under hot environment (air temperature [Ta]: 29–43 °C, dew point: 13 °C); B) thermal tolerance range of individuals from a large military group (n = 100) exposed to 35 °C/40% relative humidity were examined using thermoregulatory modeling and multivariate statistical analyses. Model simulation results assist in the decisions for the strategic planning and preventions of heat stress.	human thermoregulatory models are being developed in the military to predict physiological responses of military personnel and the probabilities of thermal-related illnesses/injuries, estimate safe thermal work times, and predict the time available for successful rescue
2006	Yoon, H.Y., and T.E. Lockhart. 2006. Nonfatal Occupational Injuries Associated with Slips and Falls in the United States. International Journal of Industrial Ergonomics 36:83-92.	The purpose of this study was to examine nonfatal occupational injury data associated with slip and fall accidents by extracting the latest information from the database of the Bureau of Labor Statistics (BLS). Systematic information on the cost and causes of industrial slip and fall accidents are not readily available from statistical and survey data sources, as such, detailed information regarding the slip-/fall-related injuries in US industries categorized by various factors are presented in this study. Nonfatal injuries resulting in days lost from work due to fall and slip were categorized by the number and incidence rate by various characteristics such as major US industry, nature of injury, source of injury, types of fall, occupation, part of body injured, age of the injured, gender of the injured and number of lost workdays utilizing the BLS database. Additionally, cost per claim associated with industrial slip and fall accidents are reviewed using the National Safety Council database. This information may be used to focus our attention toward most relevant intervention strategies associated with workplace slip and fall accidents.	Reports back injuries are quite common (23 percent of falls), though most common are to the lower extremities (33 percent).
2014	Zamanian, Z., A. Nikravesh, M.R. Monazzam, J. Hassanzadeh, and M. Fararouei. 2014. "Short-Term Exposure with Vibration and Its Effect on Attention." *Journal of Environmental Health Science and Engineering* 12135. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4241223/.	The aim of this study was to investigate the effect of vehicles vibration on cognitive performance (attention and concentration).	Cognitive performance effects related to operation of heavy equipment (vibration)
2011	Zele, A.J., Feigl, B., Smith, S.S., and Markwell, E.L. 2011. The Circadian Response of Intrinsically Photosensitive Retinal Ganglion Cells. *PLoS One* 6(3):e17860	Intrinsically photosensitive retinal ganglion cells (ipRGC) signal environmental light level to the central circadian clock and contribute to the pupil light reflex. It is unknown if ipRGC activity is subject to extrinsic (central) or intrinsic (retinal) network-mediated circadian modulation during light entrainment and phase shifting. Eleven younger persons (18–30 years) with no ophthalmological, medical or sleep disorders participated. The activity of the inner (ipRGC) and outer retina (cone photoreceptors) was assessed hourly using the pupil light reflex during a 24 h period of constant environmental illumination (10 lux). Exogenous circadian cues of activity, sleep, posture, caffeine, ambient temperature, caloric intake and ambient illumination were controlled. Dim-light melatonin onset (DLMO) was determined from salivary melatonin assay at hourly intervals, and participant melatonin onset values were set to 14 h to adjust clock time to circadian time. Here we demonstrate in humans that the ipRGC controlled post-illumination pupil response has a circadian rhythm independent of external light cues. This circadian variation precedes melatonin onset and the minimum ipRGC driven pupil response occurs post melatonin onset. Outer retinal photoreceptor contributions to the inner retinal ipRGC driven post-illumination pupil response also show circadian variation whereas direct outer retinal cone inputs to the pupil light reflex do not, indicating that intrinsically photosensitive (melanopsin) retinal ganglion cells mediate this circadian variation.	Report regarding the novel retinal receptors, sensitive to blue/green light – this subclass of retinal-ganglion cells was recently found to provide input affecting both visual sensitivity and the human sleep-arousal cycle
2013	Zhang, G., Yau, K.W., and Chen, G. 2013. Risk Factors Associated with Traffic Violations and Accident Severity in China. Accident Analysis and Prevention 59:18–25.	With the recent economic boom in China, vehicle volume and the number of traffic accident fatalities have become the highest in the world. Meanwhile, traffic accidents have become the leading cause of death in China. Systematically analyzing road safety data from different perspectives and applying empirical methods/implementing proper measures to reduce the fatality rate will be an urgent and challenging task for China in the coming years. In this study, we analyze the traffic accident data for the period 2006-2010 in Guangdong Province, China. These data, extracted from the Traffic Management Sector-Specific Incident Case Data Report, are the only officially available and reliable source of traffic accident data (with a sample size>7000 per year). In particular, we focus on two outcome measures: traffic violations and accident severity.	Observed an increase in traffic violations when it is raining, suggesting operators have difficulty allocating their attention when precipitation is present.

APPENDIX D
EXAMPLE ASSESSMENT OF IMPACTS OF ENVIRONMENTAL CONDITIONS ON A MANUAL ACTION USING IMPRINT PRO

D.1 Objective

At a training to obtain an understanding of IMPRINT Pro (ARL, 2017) functionality and methodology and how to use IMPRINT PRO to perform an assessment of the impact of environmental conditions (ECs) on a flood-protection and mitigation (FPM) manual action (MA), the U.S. Nuclear Regulatory Commission (NRC) staff and Pacific Northwest National Laboratory (PNNL) research team (together, the trainees) focused on the following objectives.

1. Gain a general understanding of IMPRINT Pro functionality and methodology.
2. Exercise IMPRINT Pro by analyzing a manual action that is expected to be performed at nuclear power plants (NPPs) under external flooding conditions.
3. Become familiar with the literature used by IMPRINT Pro to assess the impacts of environmental conditions (ECs) on human performance
4. Understand the extensibility of IMPRINT Pro software.

Section D.2 briefly describes the IMPRINT Pro software, its capabilities and applicability for assessment of impacts of environmental conditions on flood protection and mitigation manual actions. Section D.3 describes the background and assumptions, the MA, the prevailing ECs under which the MA was postulated to be performed, and the baseline performance time. Section D.4 describes the example assessment using IMPRINT Pro 4.1.

D.2 IMPRINT Pro

IMPRINT Pro is a "dynamic, stochastic, discrete event network modeling tool designed to help assess the interaction of Warfighter and system performance throughout the system lifecycle—from concept and design to field testing and system upgrades" (ARL 2017). The software provides a graphical user interface within which an analyst can build a task network model, specify operators and crews, set up criteria for successful completion of tasks, specify stressors that may affect performance, run the model under various scenarios, and generate reports. The IMPRINT Pro terminology is used in the following sections; IMPRINT Pro-specific terms are italicized and defined appropriately. IMPRINT Pro version 4.1 was used and is described in this appendix.

IMPRINT Pro is a tool developed using the Micro Saint Sharp run-time engine. The ARL owns and distributes IMPRINT Pro. There are currently approximately 400 registered users of IMPRINT Pro. A users' meeting, conducted on an approximately annual cycle, attracts about 30 participants.

The origins of IMPRINT go back to the 1970s to a U.S. Air Force concept paper and development of the U.S. Navy HARDMAN (Military Manpower verses Hardware Procurement) methodology. Development of HARDMAN II and III occurred in the 1980s, followed by development of IMPRINT and WinCrew integrated analysis environments in the 1990s. In the 2000s, IMPRINT 6 and 7 were developed. The first IMPRINT Pro version was released in 2006 with tri-services capabilities, a new user interface, and improved plug-in capabilities. IMPRINT

Pro supports both military (Army, Navy, Air Force, Marines) and non-military (National Aeronautics and Space Administration [NASA], Department of Homeland Security [DHS]) uses.

IMPRINT Pro works with multiple resource theory (MRT) and uses the concept of workload. Human performance is affected by *Performance Shaping Factors (PSFs)* that include environmental *Stressors*[1] (e.g., heat, cold), effects of personal protective equipment (e.g., *Mission-Oriented Protective Postures [MOPP],* chemical or biological protection gear), and whole-body vibration. Other *PSFs* include motion sickness, heat accumulation model, and a fatigue model. Some of these *PSFs* are built into IMPRINT Pro and some are plug-ins. IMPRINT Pro also includes personnel and training *Moderators*[2]. Florida State University has developed a training module for IMPRINT Pro. U.S. Navy Research is developing the Individualized Fatigue Module, which is based on sleep history. IMPRINT Pro assesses *Task* performance. Workers are not usually assumed to be incapacitated except for the motion sickness model.

D.3 Manual Action Used in Example Assessment

D.3.1 Background and Assumptions

Temporary flood barriers, such as sandbags, plastic sheeting, and portable panels and stoplogs, may be installed prior to or during external floods to protect important structures, systems, and components of NPPs. For example, operators at an NPP could install flood barriers on exterior walls for flood protection. The temporary flood barriers in this example are portable stoplogs, similar to those shown in Figure D.1.

The trainees made the following general assumptions about flood protection procedures and operators:

- Staffing levels at the NPP are adequate.
- Procedures for performing the actions have been demonstrated to be feasible and are established.
- Operators are trained on the procedure and use of necessary equipment.
- Operators are fit for duty including duty associated with external flooding events.
- Differences between/among individual operators are assumed to be insignificant.

The trainees made the following specific assumptions about installation of the stoplog barriers:

- Stoplog installation takes place outside, with minimal sheltering.
- Two operators need to walk or drive a short distance to location.
- Logs, bolts, and tools are staged within easy reach.
- Nine stoplogs need to be stacked per door to reach the desired barrier height for flood protection.
- Seven doors or locations need barrier installation for flood protection.

[1] *Stressors* are conditions, either in the environment or affected by protective gear that influence *task performance*.
[2] *Moderators* are algorithms that are used to estimate the effects of *PSFs* on *task* time and/or accuracy.

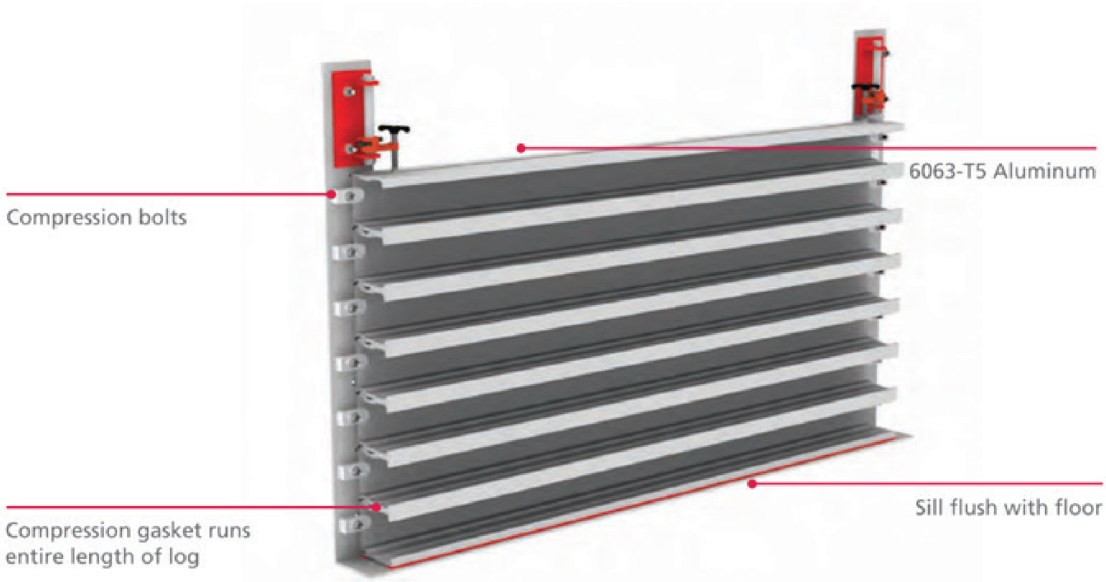

Figure D.1 Stackable stop log flood barrier (Presray 2017). *Note: this stoplog configuration is for illustration purposes only and is not intended to be a representation of actual stoplogs used at NPPs*

The trainees made the following specific assumptions about the stoplogs to be installed:

- Each stoplog is 8 in. high, stackable, and is bolted in place using one compression bolt on each side.
- Stacking the logs requires fastening each log in place with two compression bolts before adding the next log.
- Stoplogs are short and light enough to be lifted and manipulated easily by two operators (e.g., 10 ft or less in length; made with lightweight material such as aluminum).
- Stoplog channels and sill plates are permanently installed at doors of location that require flood protection.

D.3.2 The Example Manual Action

The MA used in this example assessment is “Installation of Flood Barriers on Exterior Walls.” The MA contained three tasks as shown below.

- MA: Installation of flood barriers on exterior walls
    - Task 1. Clear debris.
    - Task 2, Stage stoplogs and equipment at a staged location.
    - Task 3. Place and fasten stoplogs to protect a door to a height of 6 ft for multiple locations.

Detecting the need for and initiating (authorizing) this MA is assumed to be part of a separate action (i.e., not part of the MA). In the example, the trainees analyzed Task 3 only, which was further decomposed into subtasks and specific actions (SAs) as shown below.

Task 3: Place and fasten stoplogs to protect a door to 6 ft for multiple locations.

1. Prepare a forklift.
   - SA 3.4.a. Walk (to where forklift is parked at the stage location).
   - SA 3.4.b. Perform the Pre-Operational Check (e.g., mini safety audit before operating forklift).
   - SA 3.4.c. Climb into the forklift.
2. Move stoplogs and tools from stage location to door #1.
   - SA 3.4.d. Operate forklift (i.e., use forklift to pick up stoplogs and tools).
   - SA 3.4.e. Operate forklift (i.e., use forklift to move stoplogs).
   - SA 3.4.f. Non-electronically communicate with other personnel (to coordinate placement of stoplogs).
   - SA 3.4.g. Operate forklift (i.e., parking forklift in an accessible location to place stoplogs in position).
3. Bolt up stoplogs (for several locations). (Note: the following SAs are repeated for all 9 stoplogs for each door.)
   - SA 3.4.h. Lift log #1 from the forklift (2-person action).
   - SA 3.4.i. Place log #1 on channel and sill plate (2-person action).
   - SA 3.4.j. Use hand tools to fasten log #1 in place with two compression bolts.

Task 3 is complete for one location when SAs 3.3.a-c are completed for the 9th log (there are seven locations).

D.3.3 Prevailing Environmental Conditions

For the example, the trainees assumed that the following ECs would exist during execution of the MA, which would be carried out under unsheltered conditions:

- Precipitation intensity: 0–6 in./hr
- Water depth: 0–6 in.
- Water temperature: 60–65 °F
- Water velocity: 0–2 fps
- Wind speed: 25–45 mph
- Relative humidity: 85–95%
- Ambient temperature: 60–65 °F
- Ambient lighting: moderate to low
- Slippery ground and floating or lodged debris.

Limited ECs could be modeled with IMPRINT Pro using existing *Stressor* models that come with the software. The assessment of Task 3 of the example MA using IMPRINT Pro, which is discussed in Section D.4 , addresses only Cold. The existing *Stressor* models associated with ECs include only *Heat, Cold, Noises*, and *Whole-Body Vibration* and not all performance demands (PDs) for these *Stressors* are included.

D.3.4 Baseline Performance for Task 3

The baseline time is defined as the time it takes the operators to perform an MA in the absence of any adverse ECs. The trainees assumed that the time taken to complete the same MA under adverse ECs could be longer and is defined as the affected time. The impact of ECs is measured as the difference between the affected time and the baseline time. **Table D-1** provides the mean and the standard deviations of baseline times for the SAs. The baseline time is assumed to be distributed lognormally.

D.4 Example Assessment

The training was conducted at the PNNL Seattle offices by Alion Science and Technology on September 7 and 8, 2016. The training was attended by PNNL staff in person and via teleconferencing, by NRC staff in person and via teleconferencing, and PNNL subcontractors' staff in person and via teleconferencing. Robert Sargent of Alion conducted the training in person, with assistance from Christopher Shaw via teleconferencing. Use of IMPRINT Pro to perform an assessment of the impact of ECs on a MA is presented in the following sections as a discussion of general IMPRINT Pro functionality followed by a discussion of the modeling Task 3 of the MA.

Table D.1 Baseline time estimates for Specific Actions in Task 3

Task # 3. Place and fasten stoplogs to protect a door to 6 ft			
Subtasks	**SAs**	**Description**	**Baseline Time for One Barrier (min)[(a)]**
3.1 Prepare a forklift	3.1.a	Walk (to where forklift is parked at the stage location)	μ = 5 min σ = 0.25 min
	3.1.b	Pre-Operational Check (e.g., safety aspect before operating forklift)	μ = 2 min σ = 0.2 min
	3.1.c	Climb into forklift	μ = 1 min σ = 0.1 min
3.2 Move stoplogs and tools from stage location to the door	3.2.a	Operate forklift (i.e., use forklift to pick up stoplogs and tools)	μ = 3 min σ = 0.2 min
	3.2.b	Operate forklift (i.e., use forklift to move stoplogs)	μ = 4 min σ = 0.2 min
	3.2.c	Non-electronically communicate with other personnel (to coordinate placement of stoplogs)	μ = 2 min σ = 0.5 min
	3.2.d	Operate forklift (i.e., parking forklift in an accessible location)	μ = 2 min σ = 0.5 min
3.3 Bolt up stoplogs [Note: this subtask is repeated to build a 6-foot tall barrier]	3.3.a	Lift log # 1 from the forklift	μ = 1 min σ = 0.2 min
	3.3.b	Place log #1 on channel and sill plate (2-person action)	μ = 1 min σ = 0.2 min
	3.3.c	Use hand tools to fasten log #1 in place with two compression bolts	μ = 2 min σ = 0.1 min
μ denotes the mean, and σ the standard deviation.			

D.4.1 General IMPRINT Pro Functionality

The first day of the training focused on introduction to the IMPRINT Pro software, terminology, how to build an *Analysis*, how to assign *Tasks*, how to input *Task* data, and discussions related to some of the technical bases for impact assessment. The trainees stated that they wanted to learn (1) how background data are obtained and used in IMPRINT Pro, (2) how to add *Custom Stressors* (the *Stressors* currently implemented in IMPRINT Pro include some of the ECs), and (3) how impacts from multiple *Stressors* are combined.

D.4.1.1 Elements of IMPRINT Pro Analysis

An IMPRINT Pro *Analysis* tree consists of *Warfighters, Operations Models, Maintenance Models, Force Models*, and *Custom Performance Shaping nodes*. For the example assessment, *Warfighters, Operations Models*, and *Custom Performance Shaping* nodes were needed. Some IMPRINT Pro terms are described below.

- **Missions:** The Missions in the Analysis are task network models that represent processes to be simulated. Each model is composed of a series *of Tasks, Functions, and Goals* that are connected by a network*. Function* is a collection of *Tasks* and may be a *Subnetwork*. *Task* is the fundamental level in an IMPRINT Pro Analysis. The Mission model calculates *Task* performance times, implements appropriate *Workload*[3] strategies during operator overload, evaluates accuracy to determine *Task* failure, implements failure consequences, and collects results of *Task, Function, and Mission* performance times.
- **Operations Models:** The *Operations Models* contain processes represented by Missions, being simulated in the IMPRINT Pro *Analysis*.
- **Warfighters:** *Warfighters* are the people required to accomplish a *Mission*. For the military agencies (Army, Navy, Air Force, and Marines), IMPRINT Pro includes military occupational specialties. *Warfighters* consist of *Operators, Maintainers, and Supply and Support Personnel*. It is possible to create custom agencies and *Operators* in IMPRINT Pro for non-military *Missions.*
- **Maintenance Models:** In IMPRINT Pro, the *Maintenance Model* contains all information related to repairs including *Scenarios, Systems, and* Subsystems, and components.
- **Force Models:** *Force Models* in the IMPRINT Pro Analysis contain *Force Units*, each of which is composed of a set of *Planned* and *Unplanned Activities* and *Jobs*. This information is used to predict the manpower needed during the *Mission*. It is possible to define a pool of individuals with different skill sets and schedules within *Force Models*.
- **Stressors:** *Stressors* are conditions, either in the environment or produced by protective gear that influence Task performance. Each *Stressor*, when applied, affects *Task* time and/or accuracy during a model run.
- **Custom Performance Shaping:** All user-designed custom *PSFs* are grouped in the *Custom Performance Shaping* node within an *Analysis* and can contain *Custom Moderators* and/or *Time* Moderators. *Custom Moderators* are user-defined personnel, training, and *Stressor* modules. *Time Moderators* allow changes in the baseline *Moderators* for specified durations of time during a *Simulation.*

[3] *Workload* is the amount of effort expended by an *Operator* to perform a *Task*. *Operators* may be overloaded either because of the difficulty of the *Task* itself, distraction of multitasking, or due to the effects of ECs. *Workload* is a demand on the *Taxons*. As currently coded in IMPRINT Pro, *Taxons* do not have a demand component.

The highest level at which prescribed actions are defined is the level of a flood-protection and mitigation (FPM) procedure, comprises multiple MAs, which in turn comprise tasks, subtasks, and SAs. In IMPRINT Pro, an FPM procedure could be implemented as an *Analysis*, its MAs represented as *Missions*, with each MA (*Mission*) broken down into a network of *Tasks* that correspond to the tasks, subtasks, and SAs of the MA.

D.4.1.2 Steps in Building an IMPRINT Pro Analysis

The general steps in building an IMPRINT Pro *Analysis* are as follows:

- Define objectives.
  - For example, how much longer does a MA take to complete with an expected flood and associated ECs?
- Design the study.
  - Set up the Task network for the MA as a Mission ensuring that expected flood and associated ECs are properly accounted for.
- Collect input data.
  - Collect baseline data for Task performance times, consequences of delay or failure to perform a Task, and Operator Workload.
- Define the Mission or Missions.
  - Set up the MA as a Mission, specify the time requirement, set time and accuracy criteria, and the Mission criterion4
- Develop task data.
  - Define the task network for the mission, set time and accuracy standards, criterion, consequences of failure, effects, workload demand, taxons, and paths.
- Debug the task model.
  - Ensure completeness and consistency of the task network.
- Perform model simulation or simulations.
  - Determine expected scenarios and run the mission for those scenarios.
- Compile output.
- Analyze output.
- Present results.

IMPRINT Pro has some predefined reports including those for *Mission, Function*, and *Task* performance, *Task* timeline details, Workload strategy traces, detailed *Operator Workload*, and some plug-in–specific and *PSF*-specific reports. The software allows creation of user-defined snapshots; snapshots can be used to report values of variables at specified clock times, at the start and end of a *Task*, and when the model run ends.

In general, NPP FPM procedures are expected to encounter multiple ECs, variation of ECs with time, and variation of ECs in space. IMPRINT Pro does not directly allow for variation of ECs in time and space; however, there are ways that these effects can be included by appropriately setting up the *Missions* and *Tasks*, segmenting *Tasks* that are knowns to encounter variable ECs, and by extending IMPRINT Pro using new plug-ins.

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[4] Requirement is a limit and criterion is a measurement of success. For example, a criterion could specify that a requirement needs to be met a specified percent of times for a *Task* or *Mission* to be successful.

D.4.1.3 Coding in IMPRINT Pro

IMPRINT Pro allows use of user-written code to extend its built-in functionality. User-specified code within IMPRINT Pro is written in the programming language C#. Basic variable types include integer, floating point, Boolean, string, array, and hashtable. IMPRINT Pro contains system variables that are not editable by users and user-define variables. Variables can be accessed in the IMPRINT Pro software from the *Variables* subnode in the *Mission* node. Mathematical, comparison, and logical expressions are supported. A library of mathematical functions is also available.

IMPRINT Pro allows for checking syntax errors in user code. A syntax helper can be used to examine sample code. It is possible to use externally coded libraries from IMPRINT Pro using plug-ins.

D.4.2 Analyzing Task 3 in IMPRINT Pro

The following steps were performed in IMPRINT Pro to set up the Analysis for Task 3:

- Started IMPRINT Pro.
- Saved the default analysis, *Untitled*, as s*toplogProcedure*. This step created the new, empty Analysis, which is located on the user's computer as the file named *stoplogProcedure.imprint*. The trainees assumed that the stoplog installation task is performed by three people: one forklift *Operator* and two lifters that lift, place, and bolt stoplogs.
- In the *Analysis Tree*, the *Warfighters* node contains a default *Operator*. The trainees renamed the default operator to *Forklift Operator*, then also added two new Operators named *Lifter1* and *Lifter2*. A new *Operator Team*, *Lifter Team*, was also added and *Lifter1* and *Lifter2* were assigned to the Lifter Team. All three *Operators* were assigned a default placeholder specialty, because the trainees did not intend to use the *Personnel Moderator* functionality of IMPRINT Pro in this example *Analysis*.
- At this point, the IMPRINT Pro display looked like the one shown in **Figure D.2**.
- Right-clicked on Analysis name, *stoplogProcedure*, and selected *New Model → Operations → New Mission* to create a new *Mission* and rename it to *Install Stoplogs*. For the *Mission*, *Time Requirement* is the slowest *Mission* performance time that can be tolerated. The *Mission* criteria include a *Time Criterion* (percent of time the *Mission* performance time must meet the *Time Requirement*) and an *Accuracy Criterion* (percent of time the *Mission* must complete), with a *Time Requirement*. The trainees specified *Time Requirement* to be 90 min and left the *Mission* criteria unfilled at this time. At this point, the network diagram for the *Mission* is populated with *0 Model START* and *999 Model End Tasks* (**Figure D.3**).
- Added a dummy *Operator*, *modelTasks*, set it to be automated, and assign it to *0 Model START* and *999 Model* End *Tasks*, which are dummy *Tasks* in the sense that no real work is being performed even though they are represented as *Tasks* in the model network.
- Built the *Task network model*. The trainees determined that (1) an additional SA was needed in Subtask 3.1 to drive the forklift 600 ft from where it would initially be parked to the location where the stoplogs and tools would be staged, and (2) lifters would be in position at the door when the *Forklift Operator* brings the stoplogs. The drive time for this additional SA was assumed to be 60 s with a standard deviation of 7.5 s.

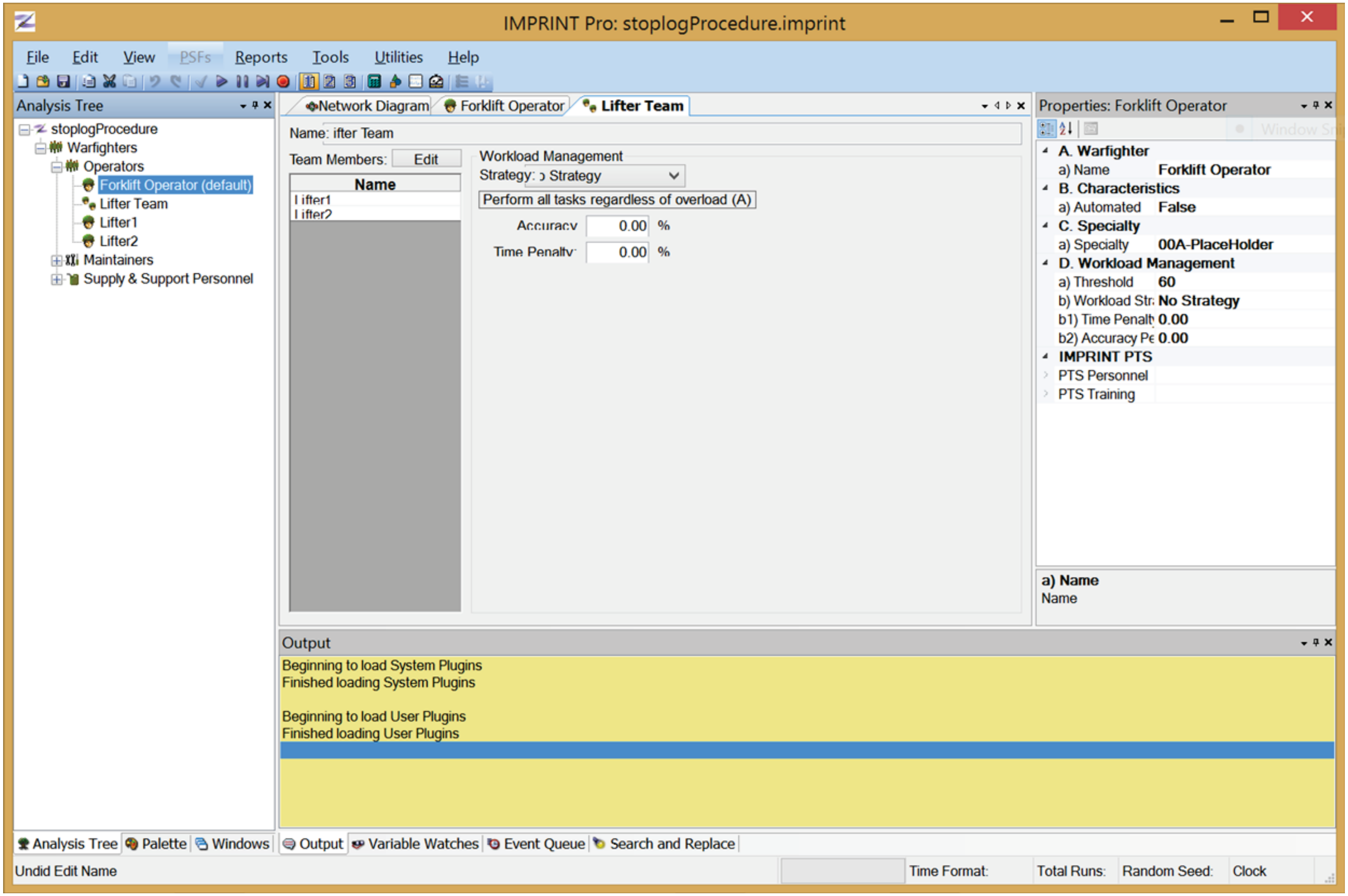


Figure D.2 **The *stoplogProcedure Analysis* with *Operators* defined**

- Added four *Tasks* that compose Subtask 3.1 in Table D.1: (1) walk to forklift, (2) perform the preoperational check, (3) climb into the forklift, and (4) drive the forklift to the stoplogs staging area. *The* Forklift *Operator* was assigned to each of these *Tasks* (**Figure D.4**).
- Added four *Tasks* that compose Subtask 3.2 in Table D.1: (1) operate the forklift to pick up stoplogs and tools, (2) drive the loaded forklift, (3) electronically communicate[1] with lifters, and (4) position the stoplogs. The trainees assumed that the communication between the *Forklift Operator* and the lifters would occur 2 min after the *Forklift Operator* starts driving the loaded forklift to the door. Another task*, Comm time delay*, was added to the network model and *modelTasks* was set as its *Operator*. The trainees also added another *Task* for the lifters (specifically *Lifter1*) to communicate with the *Forklift Operator*. At this point, the network model appears as shown in **Figure D.5**.
- At this point in the development of the *network model*, the trainees noted that as modelled the communication between the *Forklift Operator* and the lifters did not seem to affect performance time. To allow potential problems with communications to affect overall performance time, *Communicate with lifters* and *Communicate with forklift operator Tasks* were connected to *the Position stoplogs task*. The trainees also added three Boolean variables to the model—*driveRejoin, commWithLiftersRejoin*, and *commWithForkliftOperatorRejoin*—these variables are used to represent completion of the *Tasks Drive loaded forklift, Communicate with lifters*, *and Communicate with forklift operator*, respectively (**Figure D.6**). Initially, all three variables are set to false.
- For *Drive loaded forklift Task*, *the Ending Effect* code was changed in IMPRINT Pro to set its corresponding completion status variable to true (**Figure D.7**). Similarly, *Ending Effect* codes for *Communicate with lifters* and *Communicate with forklift operator tasks* were also changed to set their respective completion status variables, *commWithLiftersRejoin*, and *commWithForkliftOperatorRejoin*, to true.
- To ensure that the three Tasks, Drive loaded forklift, Communicate with lifters, and Communicate with forklift operator, completed before stoplogs can be appropriately positioned, the Release Condition code for the Task Position stoplogs was changed to check that each of the three Tasks preceding it were completed (**Figure D.8**). This configuration allows a delay or a failure of communications Tasks to affect overall performance time.
- Added three *Tasks* that composed Subtask 3.3 in Table D.1: (1) lift the stoplog from the forklift, (2) place the stoplog, and (3) fasten the compression bolts. The *Lifter Team* is assigned to these three *Tasks*. The three *Tasks* composing Subtask 3.3 need to be performed nine times to before placing and fastening all stoplogs are complete. To code in the loop for the three *Tasks*, the trainees added an integer counter variable, *counterStoplogInstal*l. The counter variable is initially set to 0. It needs to be incremented by one after successful fastening of the compression bolts for each stoplog. Therefore, the *Ending Effect* code for the *Fasten compression bolts Task* was changed to increment the stop log install counter by one (**Figure D.9**).
- To exit the loop, stop after the last of the nine stoplogs is placed and fastened, the *Fasten compression bolts Task* was connected to the *Model END task.* At this point, the *Fasten compression bolts Task* has multiple paths: one going back to *Lift stoplog from forklift* and the other to *Model END* (**Figure D.10**). The *Fasten compression bolts Task's* path decision was changed to *Tactical* (**Figure D.11**). Using *Tactical* path decision allows user-specified code to control which path is taken at the end of *Fasten compression bolts Task.*

[1] The trainees decided to change the communication from non-electronic to electronic communication to allow demonstration of how IMPRINT Pro can be used to model concurrent activities.

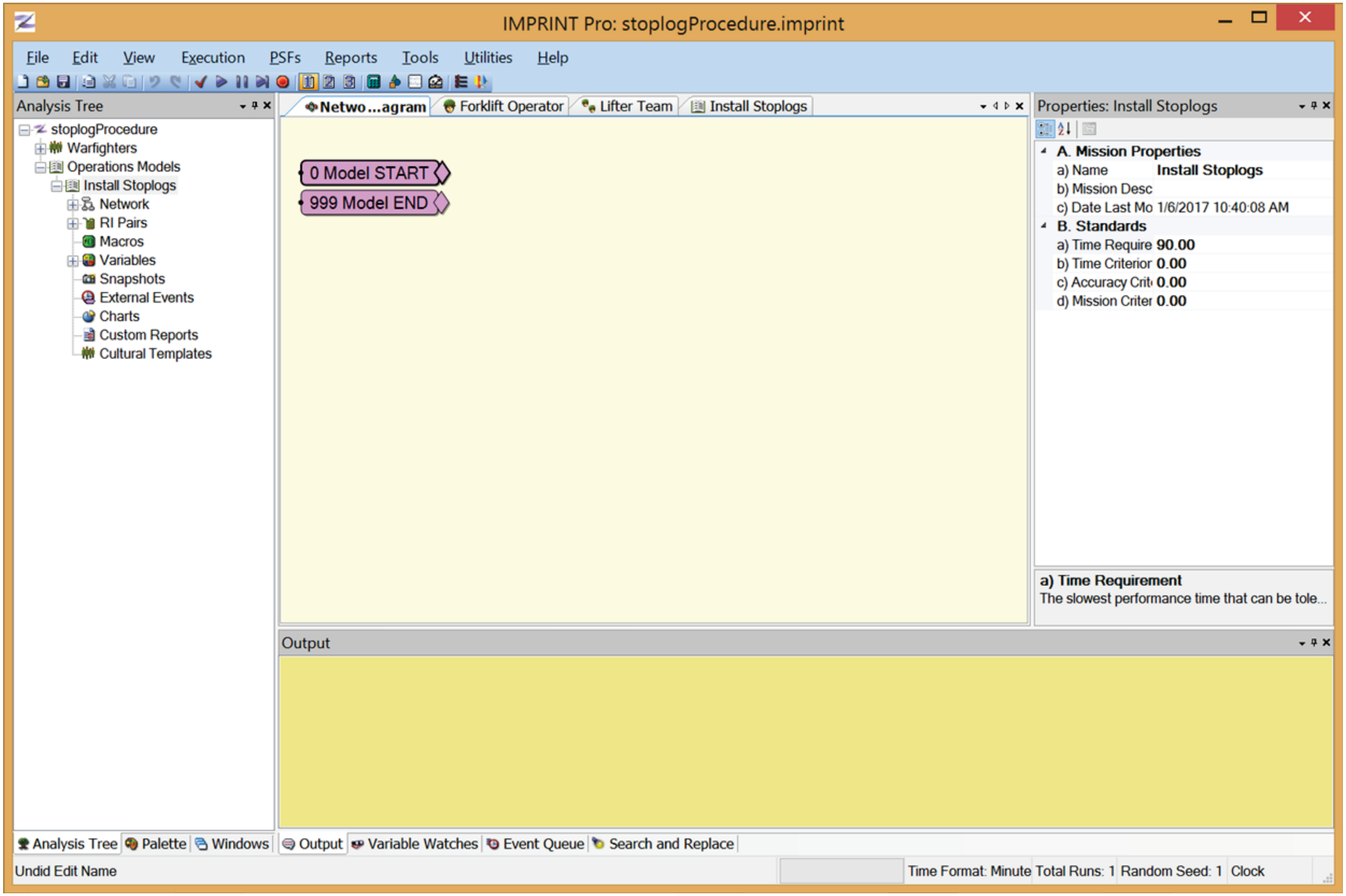


Figure D.3 The *stoplogProcedure Analysis* with *Install Stoplogs Mission*

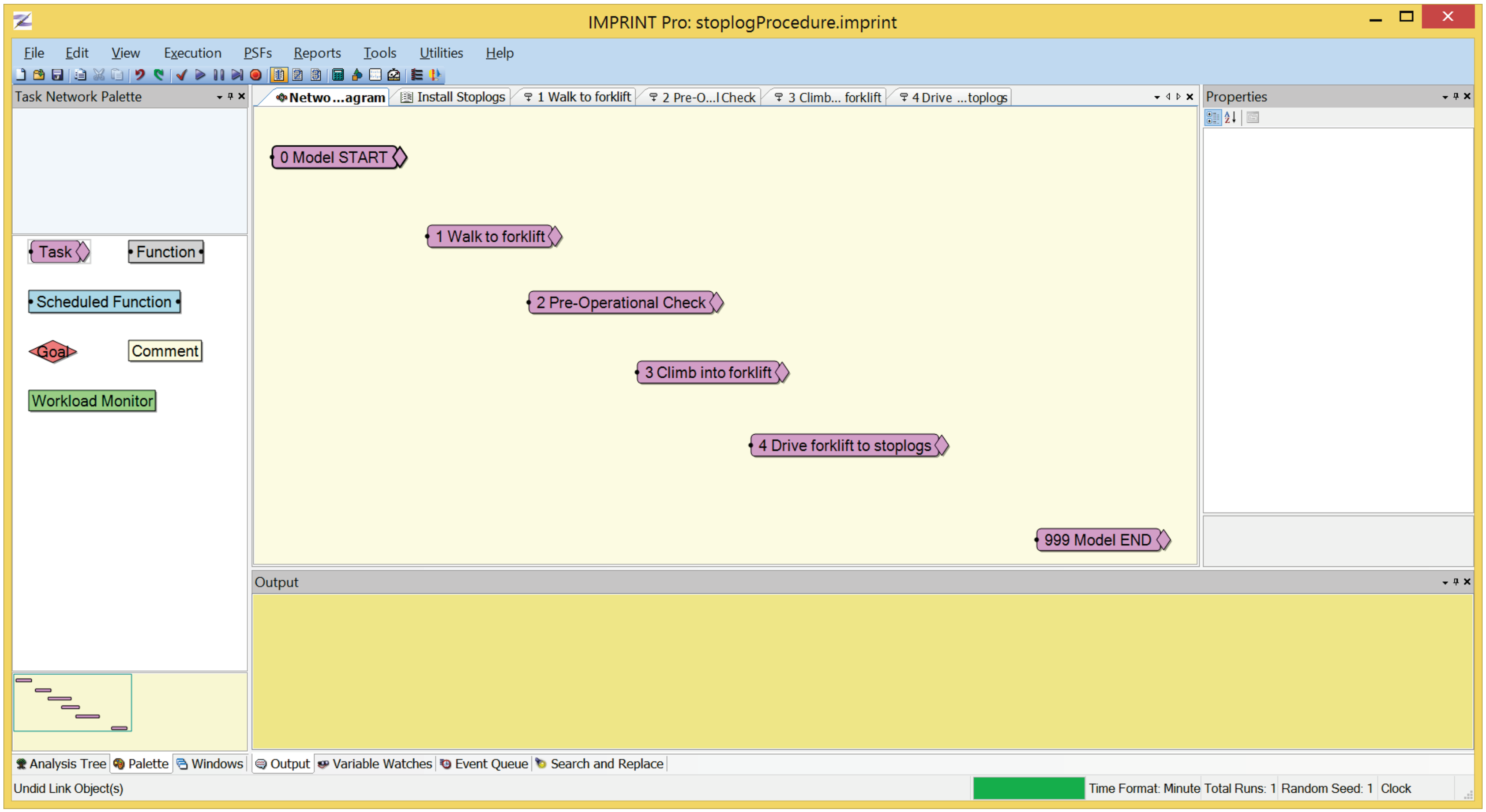


Figure D.4 Specific Actions of Subtask 3.1 created in the *Task* network

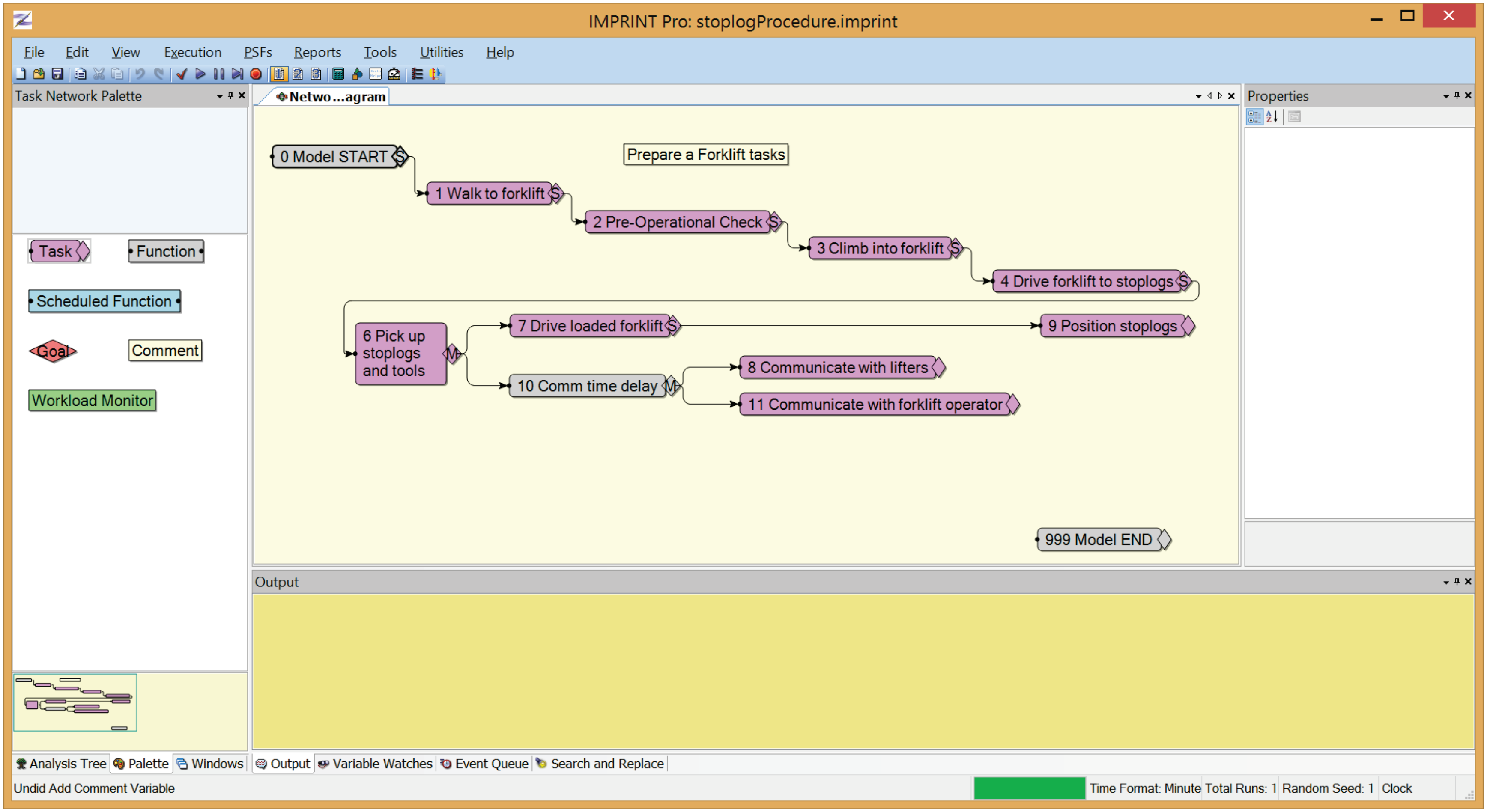


Figure D.5 Network Model after partial implementation of Subtask 3.2

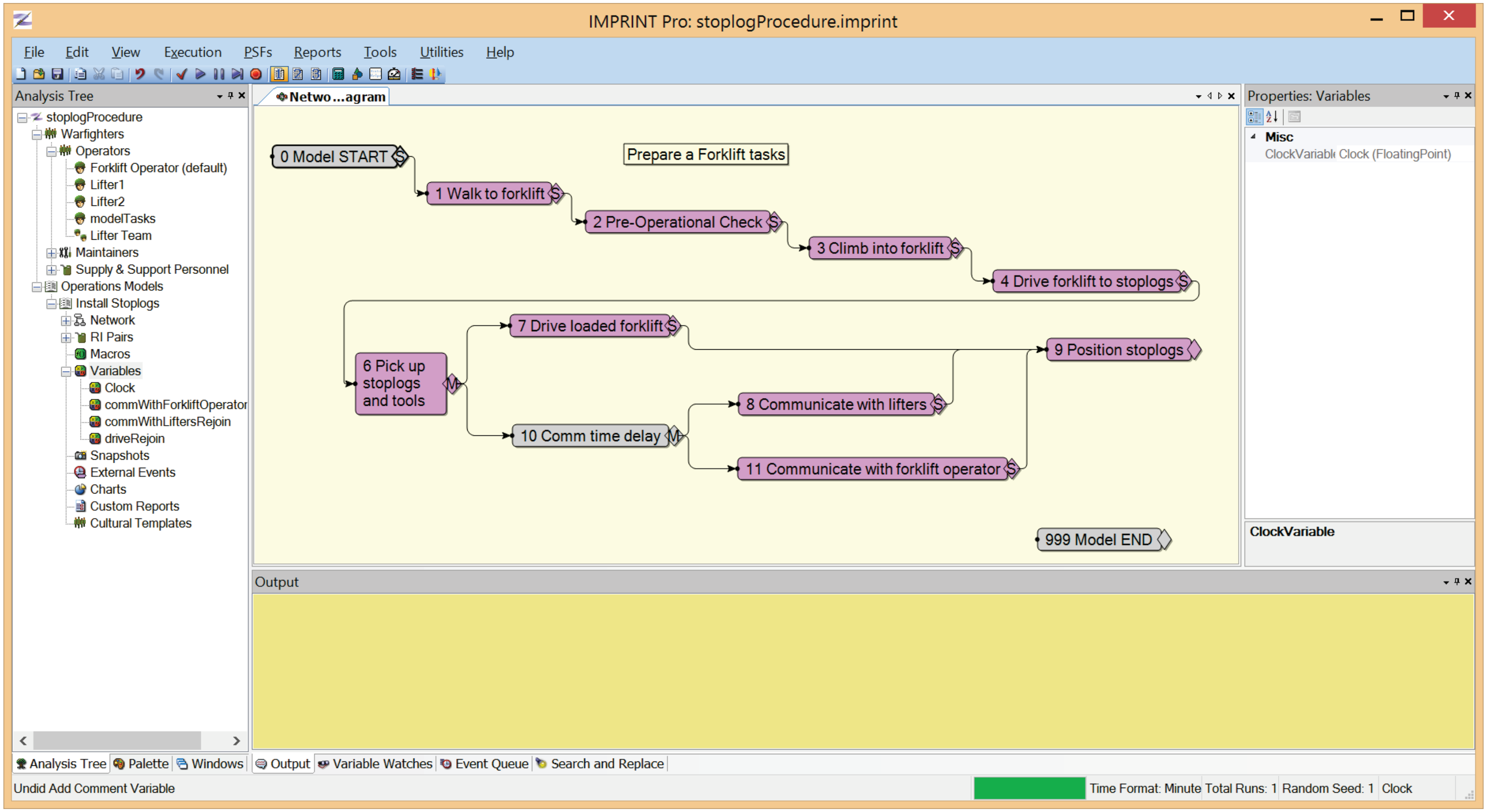


Figure D.6 Communications *Tasks* connected to *Position stop logs Task* and status variables

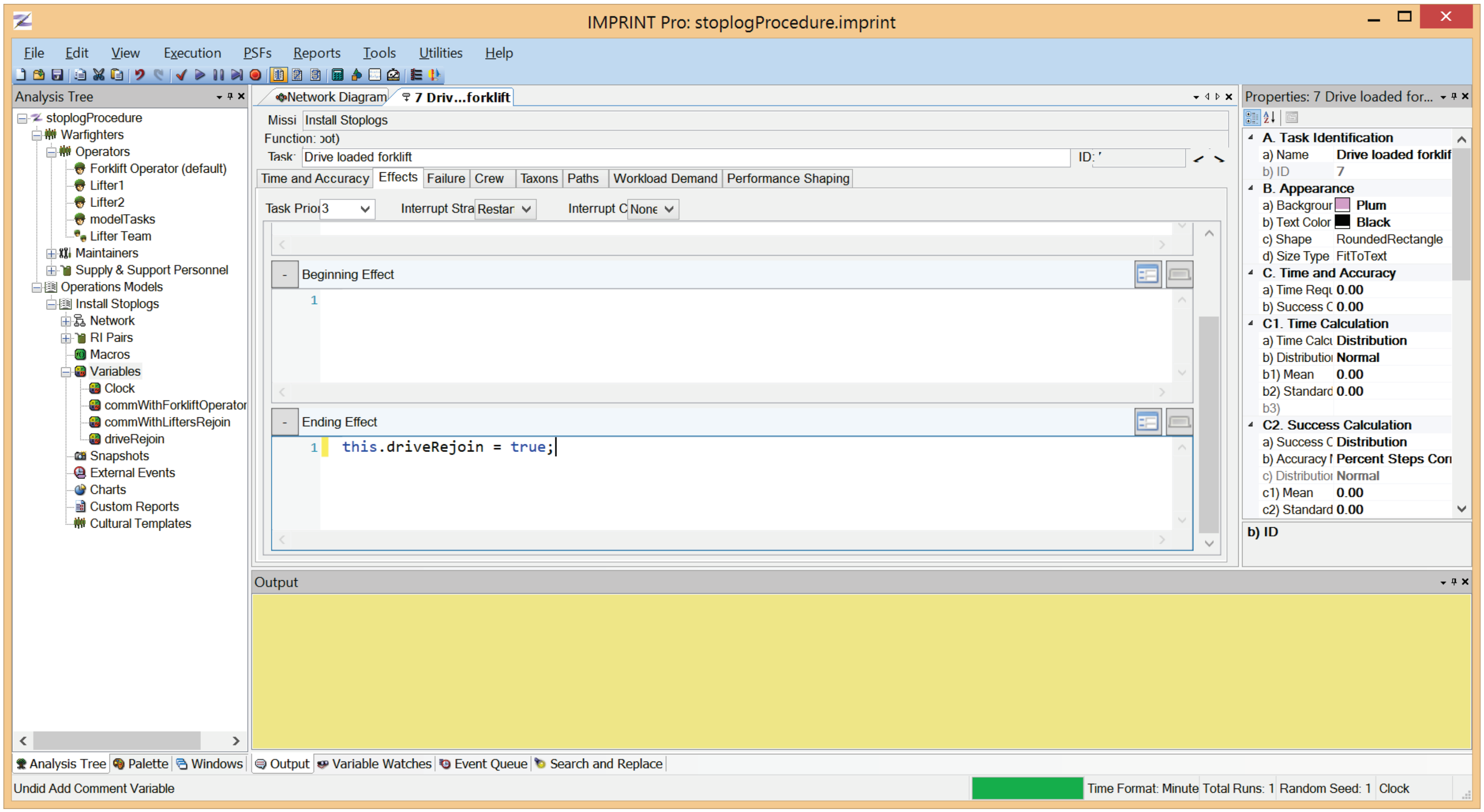


Figure D.7 ***Ending Effect*** **code for** ***Drive loaded forklift Task***

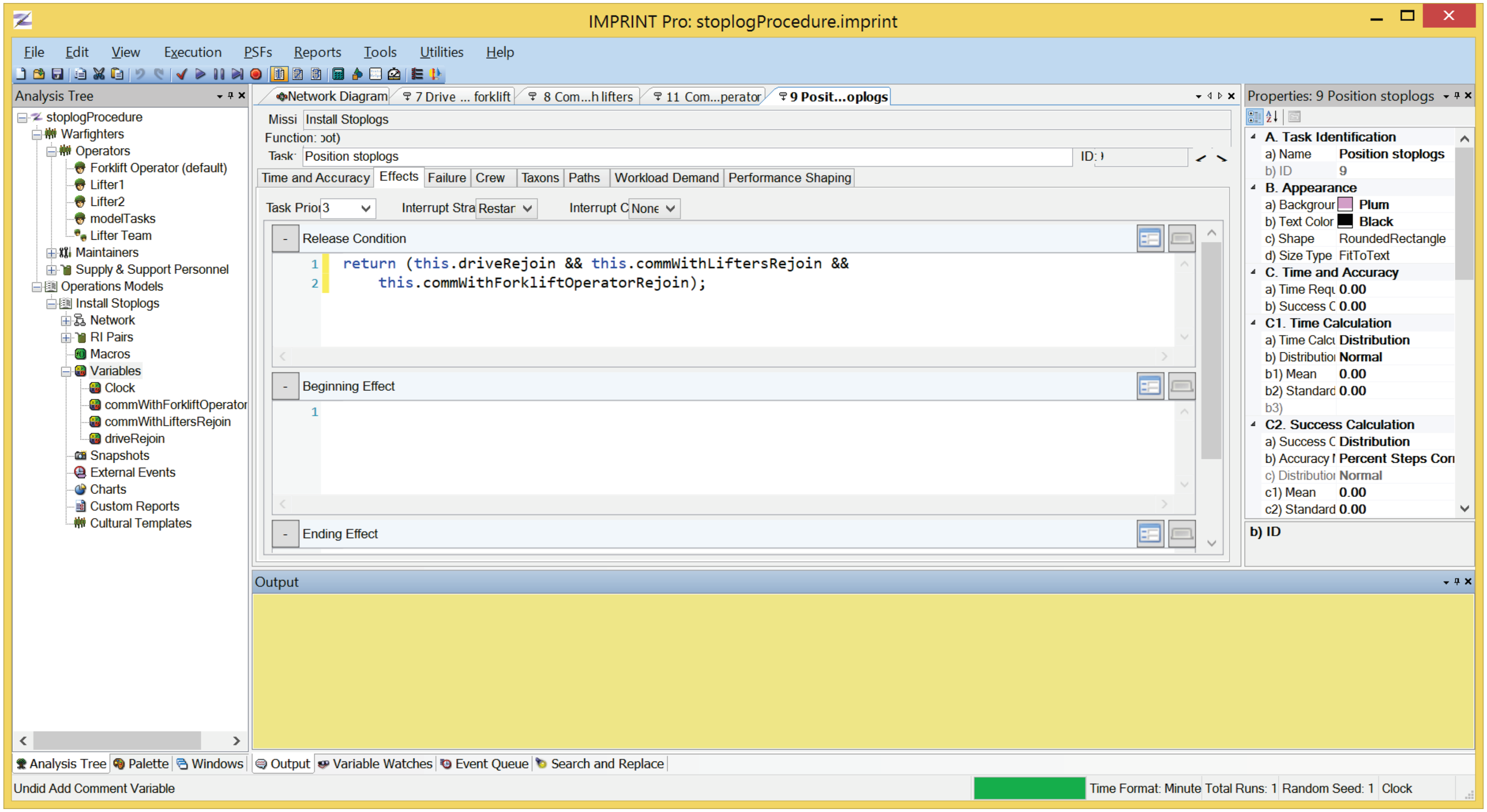


Figure D.8 ***Release Condition*** **code for** ***Position stop logs Task***

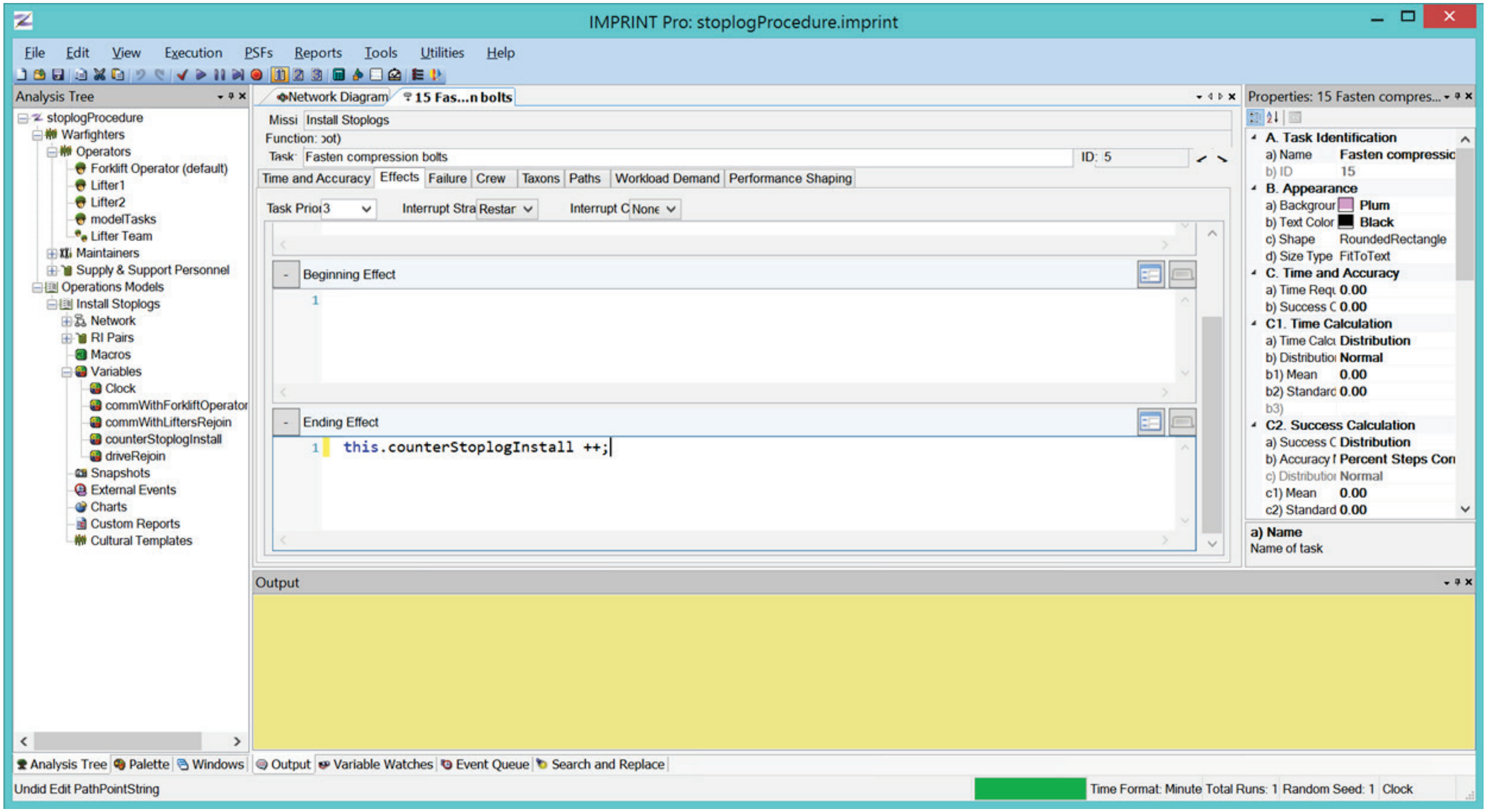


Figure D.9 *Ending Effect* code to increment *counterStoplogInstall*

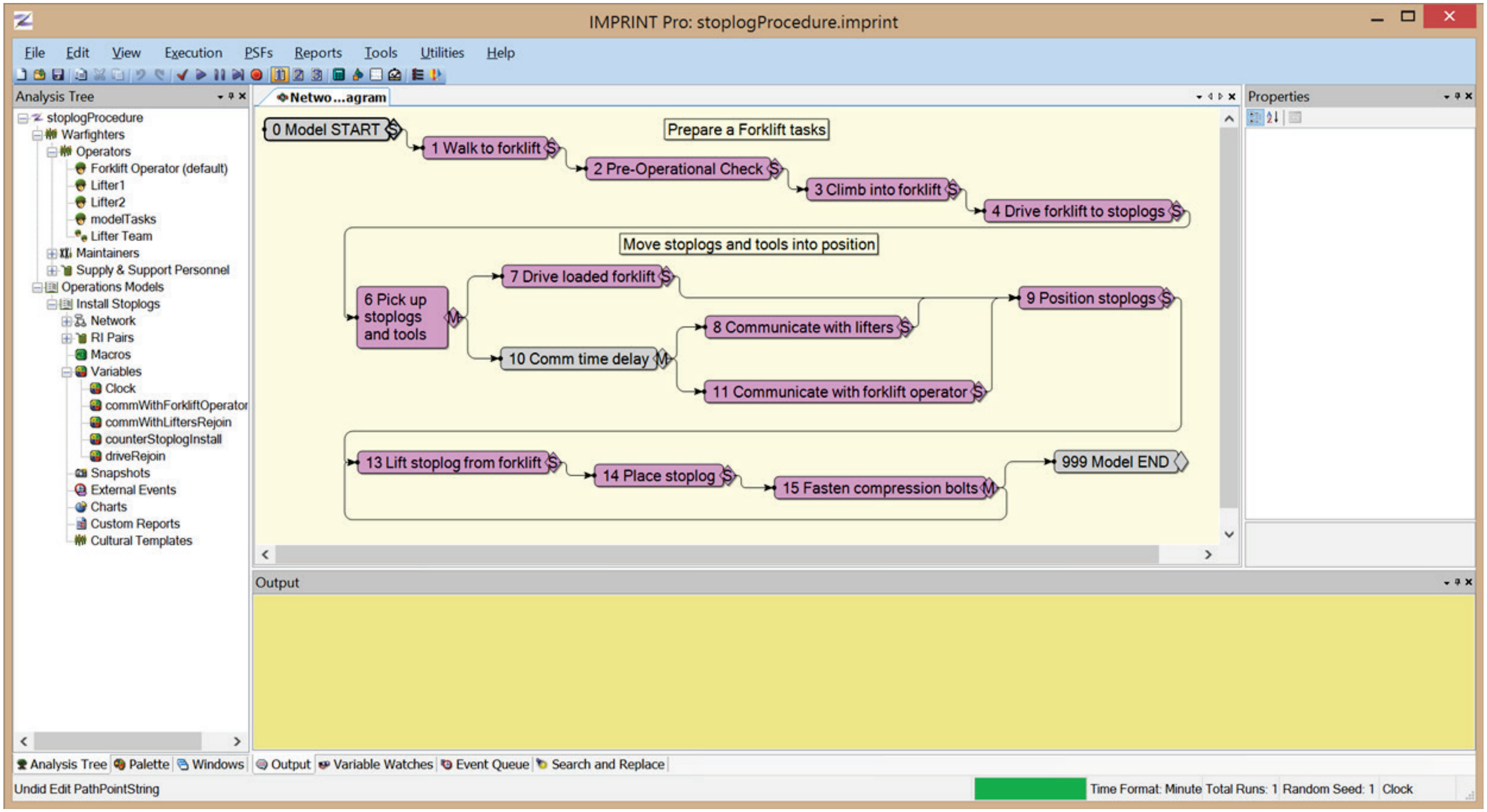


Figure D.10 Loop to install stoplogs and exit path to *999 Model END Task*

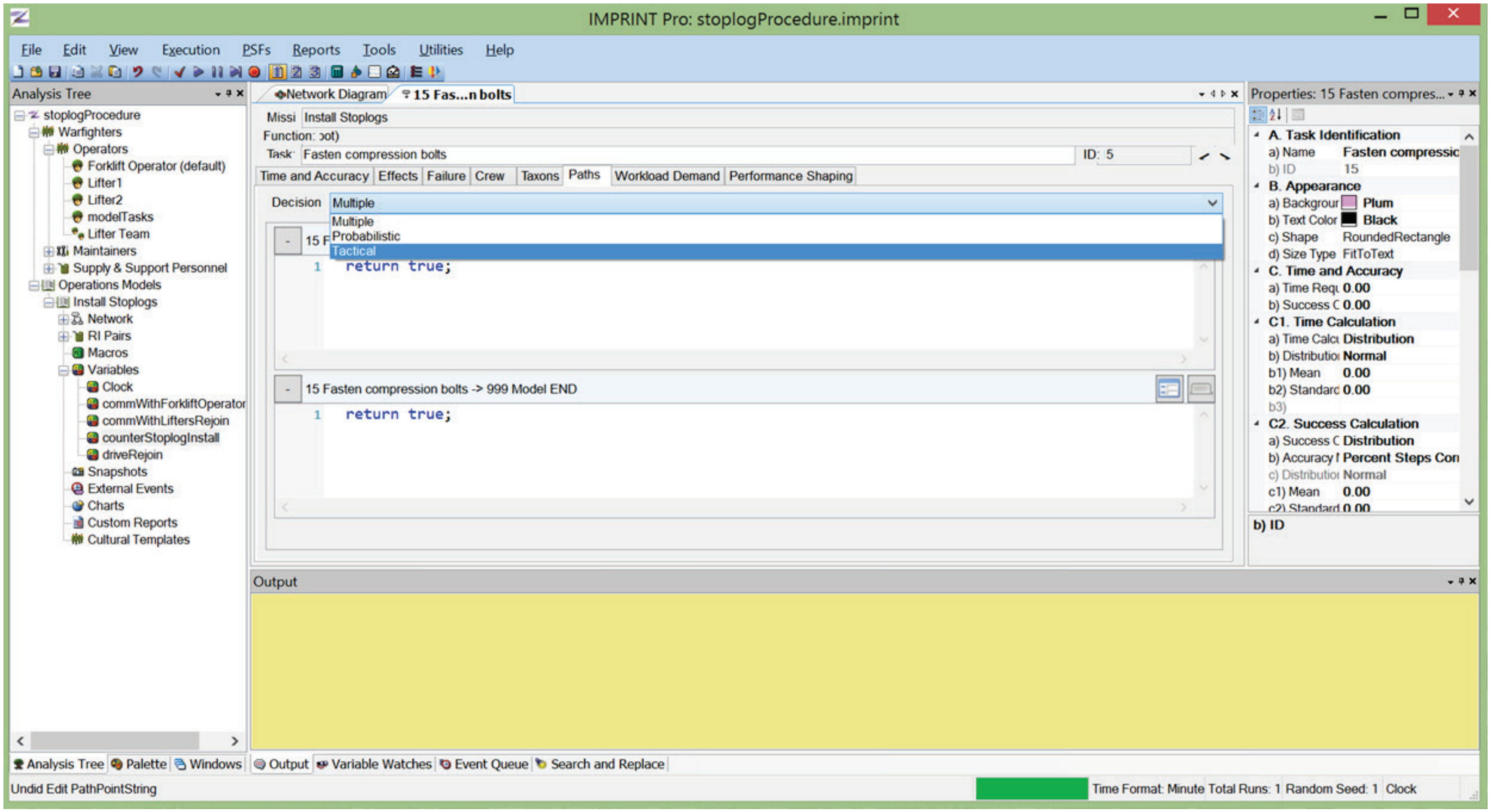


Figure D.11 *Fasten compression bolts Task*'s path decision changed to *Tactical*

- The *Tactical* decision code for the path *Fasten compression bolts → Lift stoplog from forklift* was changed to allow that decision to evaluate to true as long as the value of the counter variable *counterStoplogInstall* is less than 9. The code for the path *Fasten* compression *bolts → 999 Model END* was changed to allow that decision to evaluate to true when the value of the counter variable *counterStoplogInstall* becomes 9 or greater (**Figure D.12**). **Figure D.13** shows the final *network model*.

The following steps were performed to enter the *Task*-related data into IMPRINT Pro:

- The *Task* Network tab was opened in IMPRINT Pro by double-clicking on the Network element of the Analysis Tree. The *Task* Network tab contains a table to enter *Task*-related information. The table was customized to only select relevant elements. As stated in Section C.5, the distribution of SA performance baseline times is assumed to be lognormal. The baseline time data for the SAs (*Tasks*) were entered into the *Task* Network tab's *Task* Info table (**Figure D.14**).
- The model was checked for possible syntax errors by clicking the red check mark on the toolbar (or alternatively via the menu item *Execution → Check for Errors*). The model passed the syntax error check successfully.
- The model was executed once by clicking the blue play icon on the toolbar (or alternatively via the menu item *Execution → Begin Simulation*). The model ran to completion successfully (**Figure D.15**). The model was also executed 100 times by setting the *Number of Times to Run the Mission* to 100 on the *Operational Settings* tab of the *stoplogProcedure mission (*use the menu item *Execution → Settings*). All 100 runs were completed successfully.
- The results from the 100 test runs were generated. *Mission Performance, Mission Results by Run*, and *Mission Results - Chart* were selected for the output report. **Figure D.16** shows the output for the 100 test runs.

The next step in the *Analysis* was to specify *Crew Workloads or Taxon* assignments for the *Tasks*. The following steps were performed:

- In the *Analysis Tree*, the trainees double-clicked the RI Pairs item *of Install Stoplogs Operations Models*. On the *RI Pairs* tab, in the *Channels* table, we selected *Auditory, Cognitive, Fine Motor, Gross Motor*, and *Visual* resources that the *Operators* are expected to use (**Figure D.17**).
- On the *RI Pairs* tab, in the *Conflicts* table, we selected each row by clicking each *RI Pair* and click *Auto* button to populate default conflict values for the row (**Figure D.18**). Conflicts occur when an *Operator* is engaged in multiple activities simultaneously.
- Trainees double-clicked on the *Network* item of *Install Stoplogs Operations Models* in the Analysis *Tree* to bring up the *Task Network* tab and select the radio button for *Task Demands*. The *Task Demand* values for each *Task* were then selected from IMPRINT Pro scale of 0 to 7. For example, *Walk to forklift Task* was assigned a *Task Demand* of 2 for *Gross Motor* (corresponding to IMPRINT Pro benchmark *Walking on uneven terrain*) and a *Task Demand* of 3 for *Visual* (corresponding to IMPRINT Pro benchmark *Inspect/Check*) resources. At this time, the trainees decided to not use the *Workload* or *Task Demands* approach because using it is not necessary to estimate the additional time required to perform the task under the effects of the ECs. The *Task Demands* entered into IMPRINT are used to automatically map into *Taxon* allocations for *Tasks*. The trainees

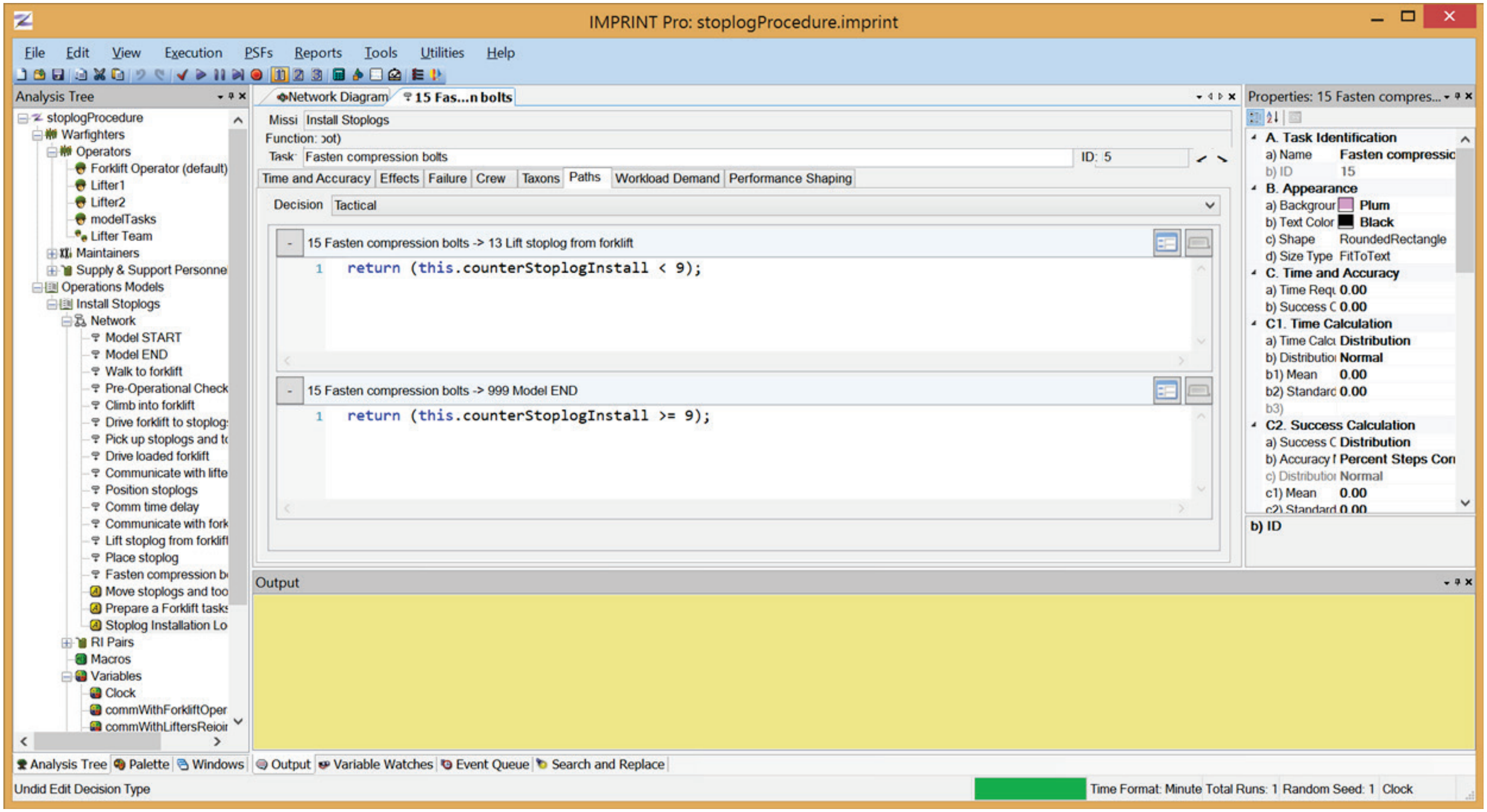


Figure D.12 Decision codes for paths from *Fasten compression bolts Task*

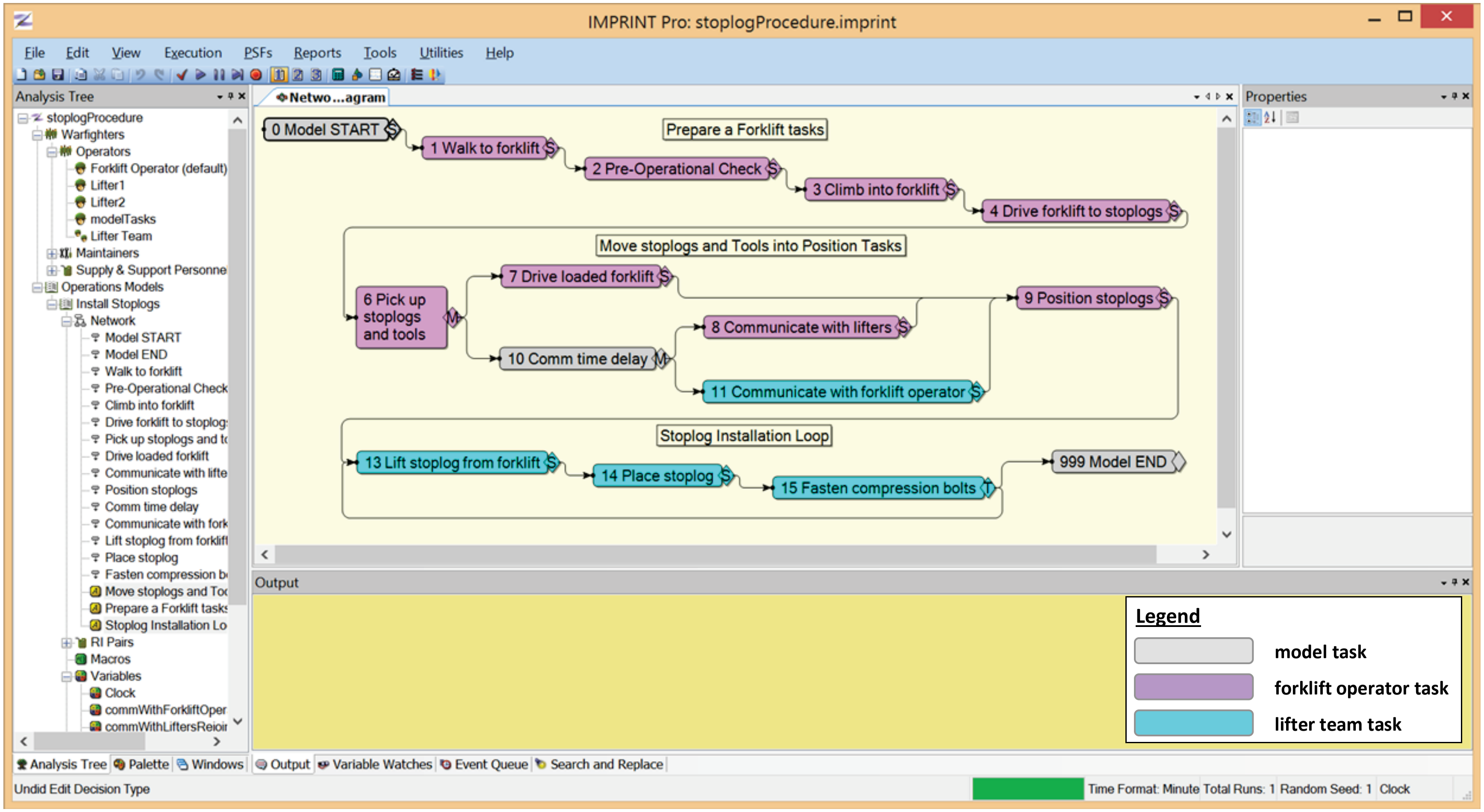


Figure D.13 The final network model including model tasks, and operator tasks

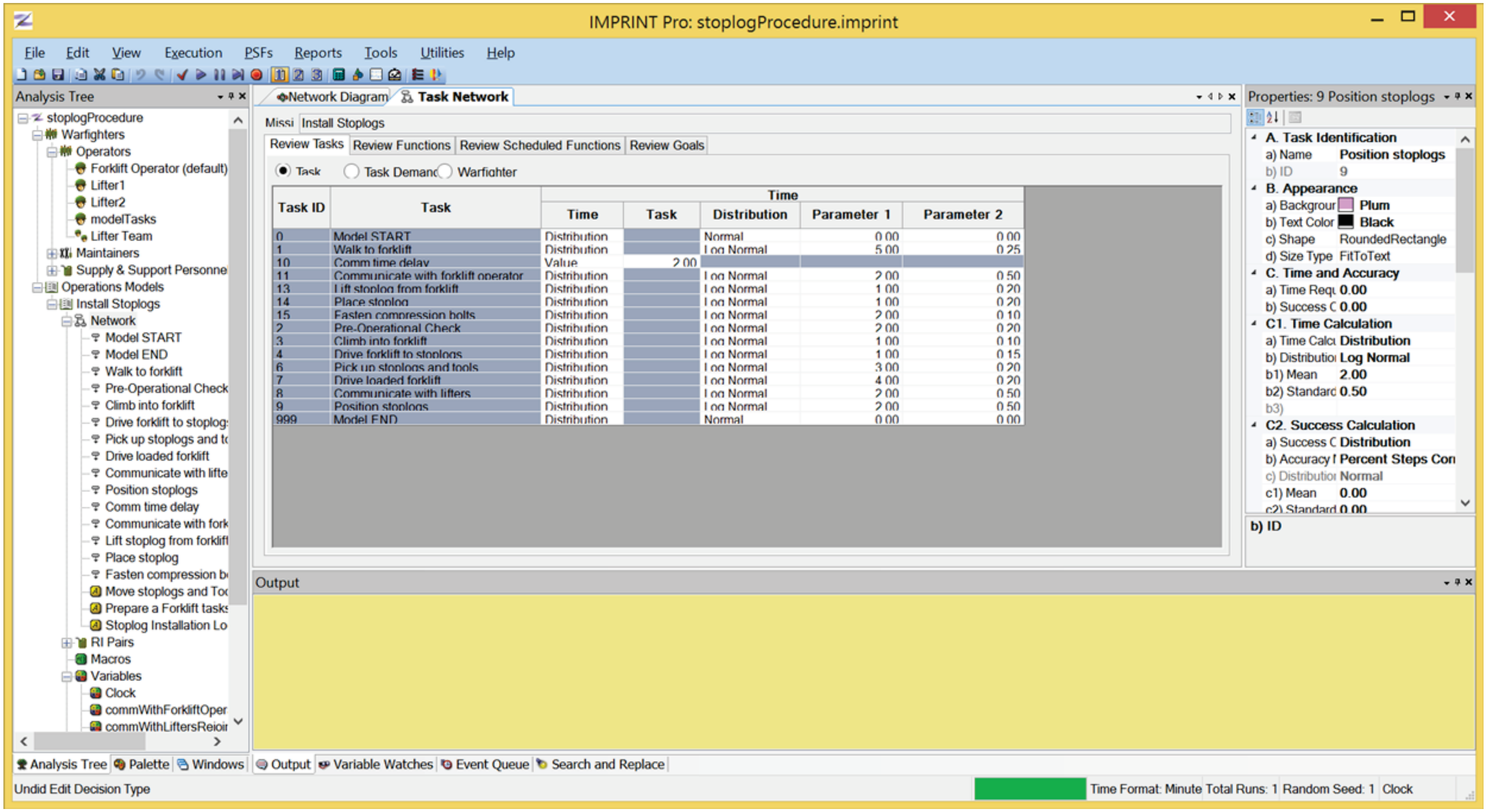


Figure D.14 Task Info table in Task Network tab with SA performance baseline times

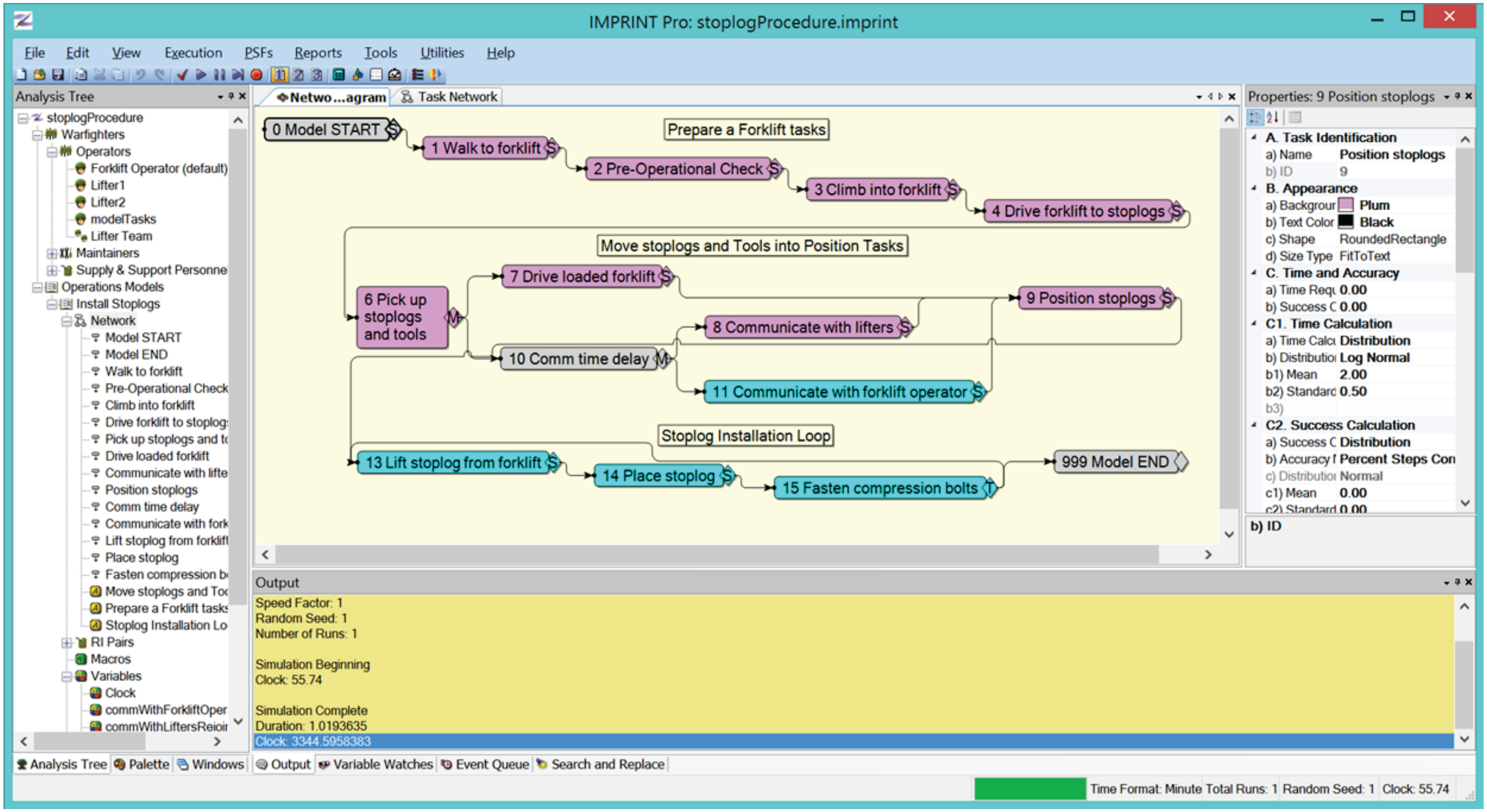
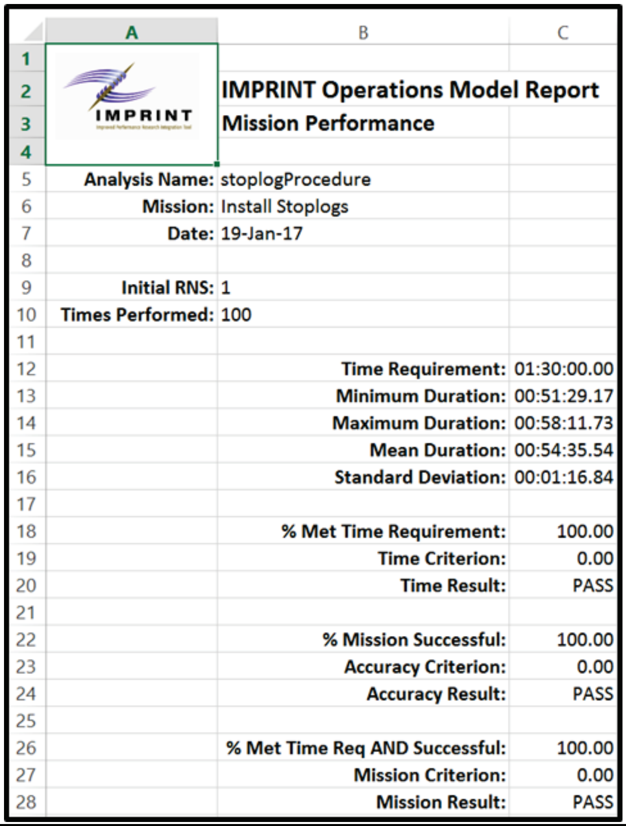


Figure D.15 One test run of the model performed after checking for syntax errors



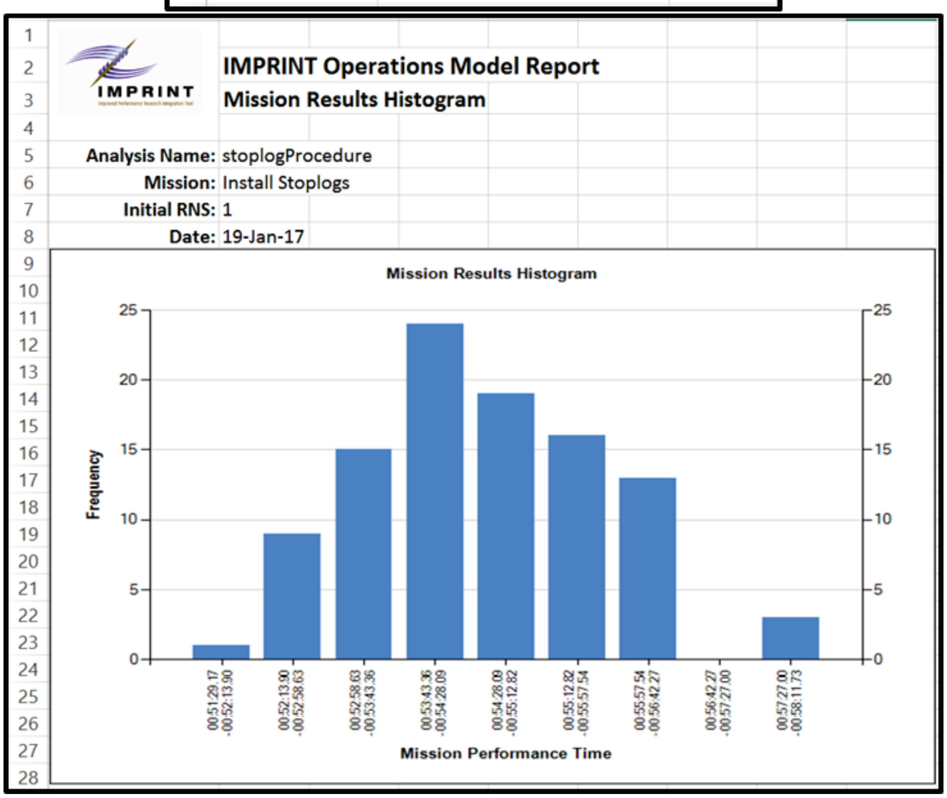


Figure D.16 **Output from 100 test runs of *stoplogProcedure.* These runs demonstrate the distribution of baseline performance times.**

- decided to directly assign the *Taxon* allocations to *Tasks* because this approach is more directly related to the framework developed for "Effects of Environmental Conditions on Manual Actions for Flood Protection and Mitigation" and introduced in Coles et al. (2017).
- To directly allocate Taxons to Tasks, the Task Info table of the Task Network tab was selected and the Task info table was customized to only include columns Task ID, Task, Taxon 1 ID, Taxon 1 Weight, Taxon 2 ID, Taxon 2 Weight, Taxon 3 ID, and Taxon 3 Weight (**Figure D.19**). Taxons and associated weights were assigned to each Task. For example, for the Walk to forklift Task, weights of 0.7 and 0.3 were assigned to the Taxons Gross Motor – Light and Visual Recognition / Discrimination, respectively. **Figure D.20** shows the IMPRINT interface for assigning Taxon weights to Tasks. Each Task can have up to three Taxons and the three Taxon weights should add up to 1.0. **Figure D.21** shows the final Taxon assignments for all Tasks.

D.4.2.1 Applying a Built-in Stressor to stoplogProcedure

The *stoplogProcedure* model was then subjected to *Cold*, a *Stressor* already present in IMPRINT Pro. IMPRINT Pro has only a limited set of built-in *Stressor* models for a limited set of *Taxons* (see **Figure D.22**). The following steps were performed:

- In IMPRINT Pro, the trainees clicked on the *PSFs* menu item to bring up the *Performance Shaping* tab, which shows all *Stressors* available to the software (**Figure D.23**). *PSFs* were enabled for all *Tasks* in the *Task Data* table within the *Performance Shaping* tab. *Cold* was applied by specifying the temperature to range from 15 to 32°F and wind to range from 21 to 30 kt for all *Tasks* (**Figure D.24**). In this analysis *Stressor* severity is assumed to be constant with time as the *stoplogProcedure* is performed.
- The trainees noted that the effects of *Cold* on Subtask 3.1 were not substantial. Potential reasons for this are that (1) *Cold* does not appreciably affect the *Taxons* that compose the major part of Subtask 3.1; (2) the impact of wind speed, specified as part of *Cold*, affected only the effective temperature and was not treated as a *Stressor* itself; (3) the assessment of the impact of *Cold* assumes use of protective gear to mitigate the effects of low temperatures; and (4) only one *Stressor*, *Cold*, was considered.
- Before IMPRINT Pro runs can apply the *Stressors* to the *Mission, PSF Adjustmen*ts must be enabled on the *stoplogProcedure Operator Settings* tab. The *stoplogProcedure* tab was brought up via the *Execution → Settings* menu item and the checkbox for *Enable PSF Adjustments* was selected (**Figure D.25**).
- The *stoplogProcedure* was run 100 times with the *PSFs* enabled and reports were generated again. The reports included *Mission Performance, Mission Results by Run*, *Stressor Settings*, and *Mission Results - Chart* (**Figure D.26**). The *Mission Performance* and *Mission Results* histogram are shown in **Figure D.27**. The mean *Mission* performance time for the baseline run was 54 min 36 sec (**Figure D.16**) and the mean *Mission* performance time with *Cold* applied increased to 57 min 4 sec (**Figure D.27**), an increase of 2 min 28 sec. It should be noted here that IMPRINT Pro models the range of temperatures and wind speeds associated with the *Stressor Cold* as a category and that performance degradation within a category is the same. The distribution of *Mission* performance times in **Figure D.27** only represents variability from SA performance times specified in **Table D.1**.

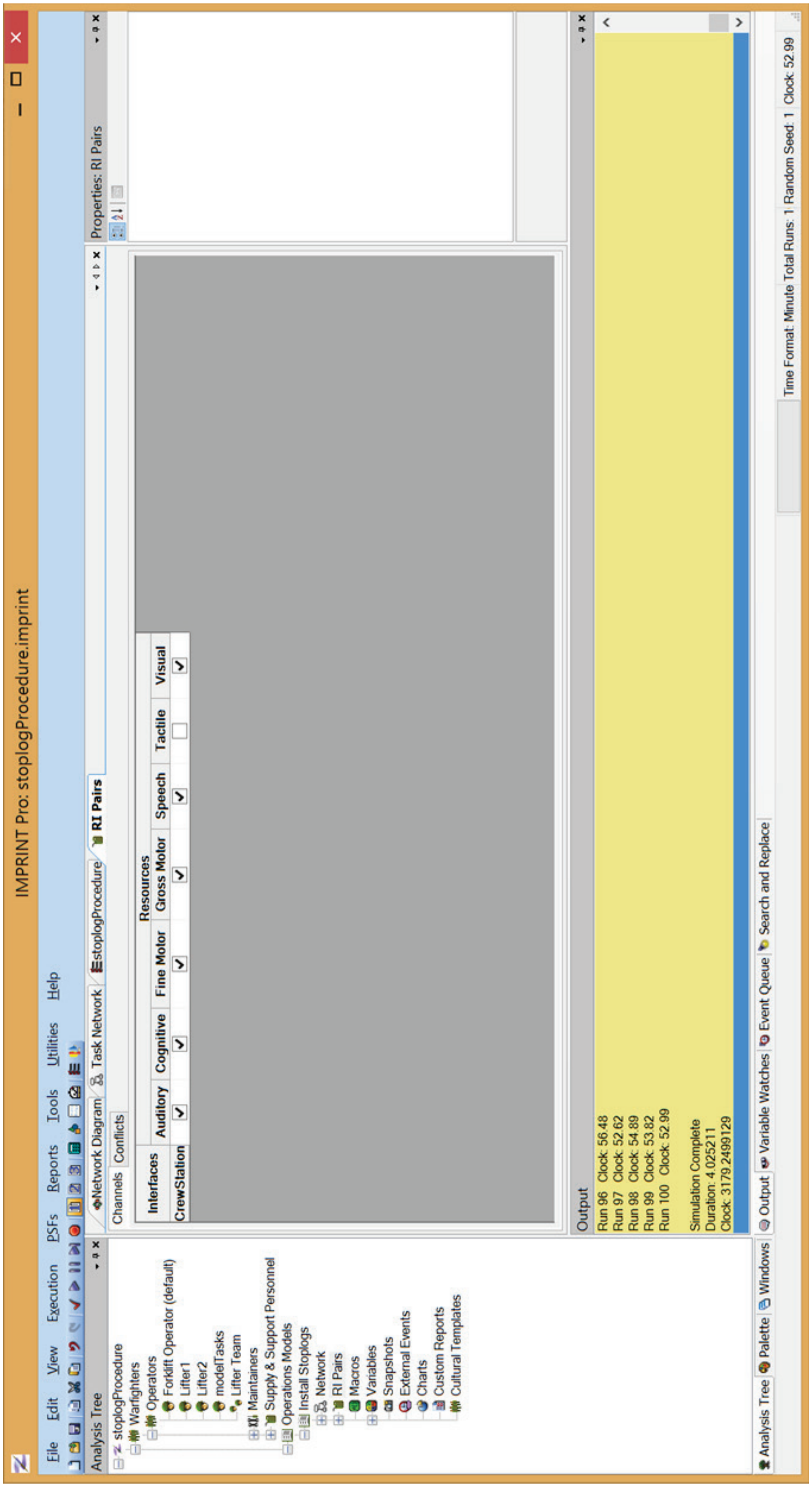


Figure D.17 ***RI Pairs*** **– selecting** ***Resources*** **that** ***Operators*** **are expected to use**

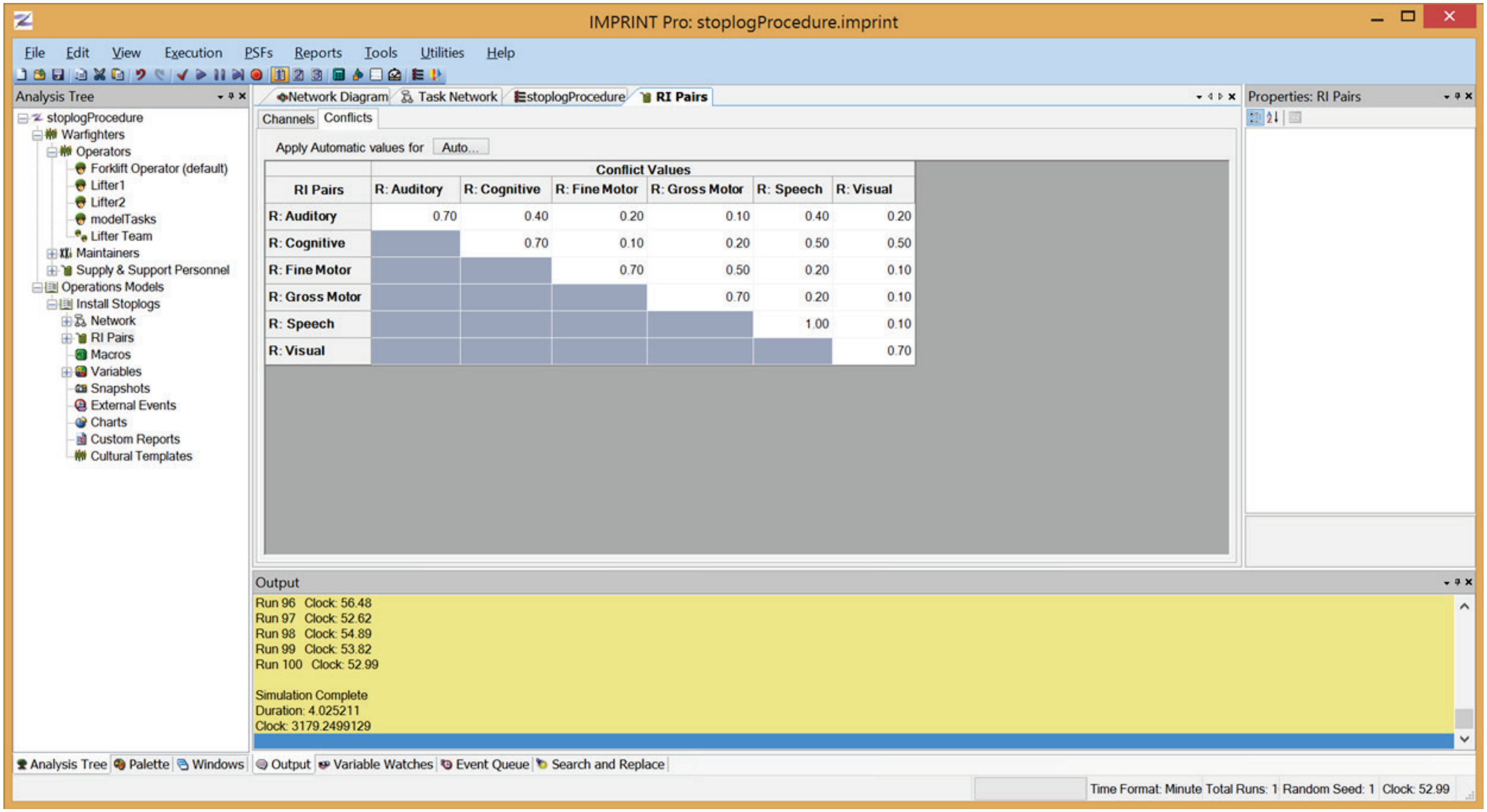


Figure D.18 *Resource Conflict* values for selected *Resources* specified as IMPRINT Pro defaults

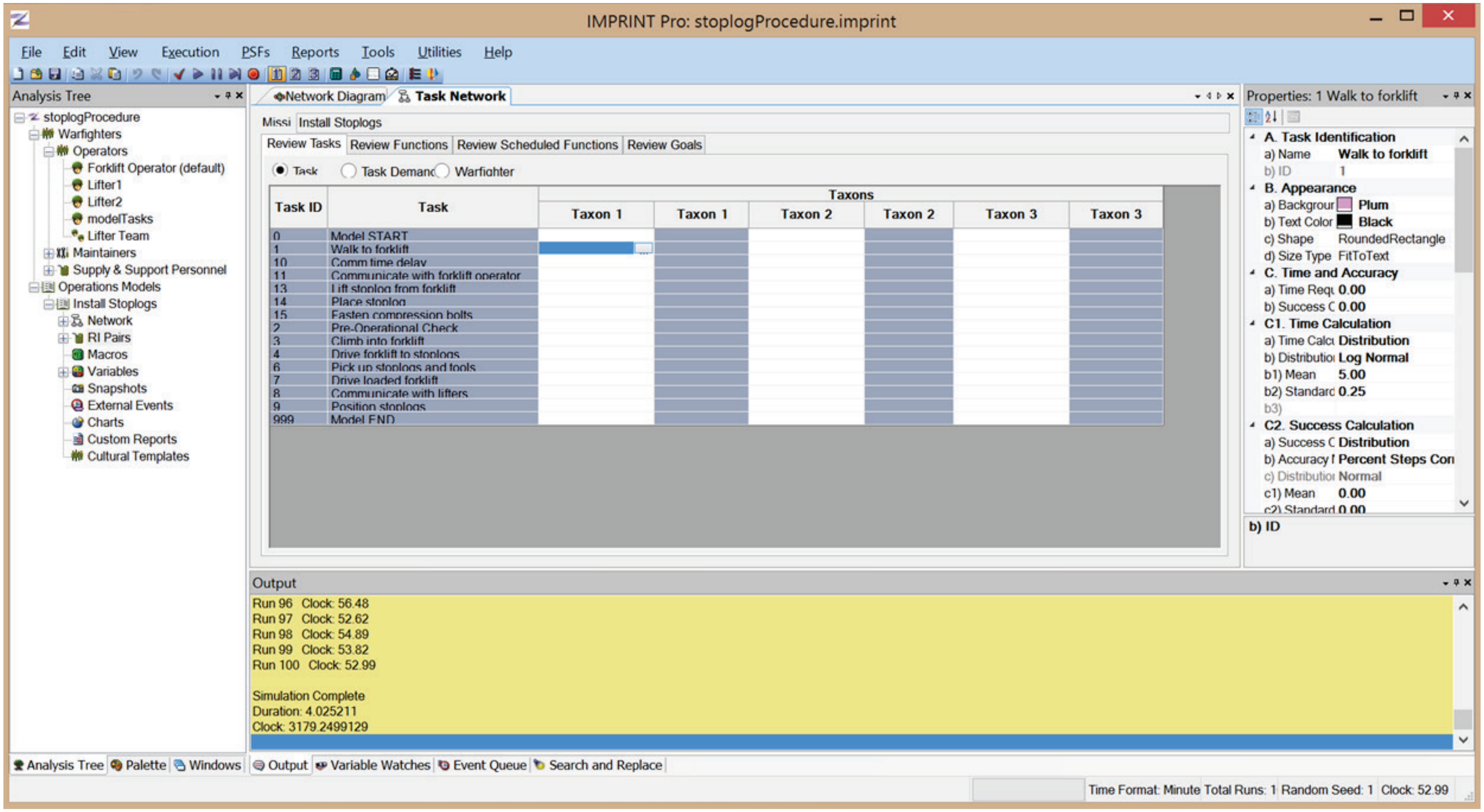


Figure D.19 The *Task Info* table configured to directly assign *Taxons* and associated weights to *Tasks*

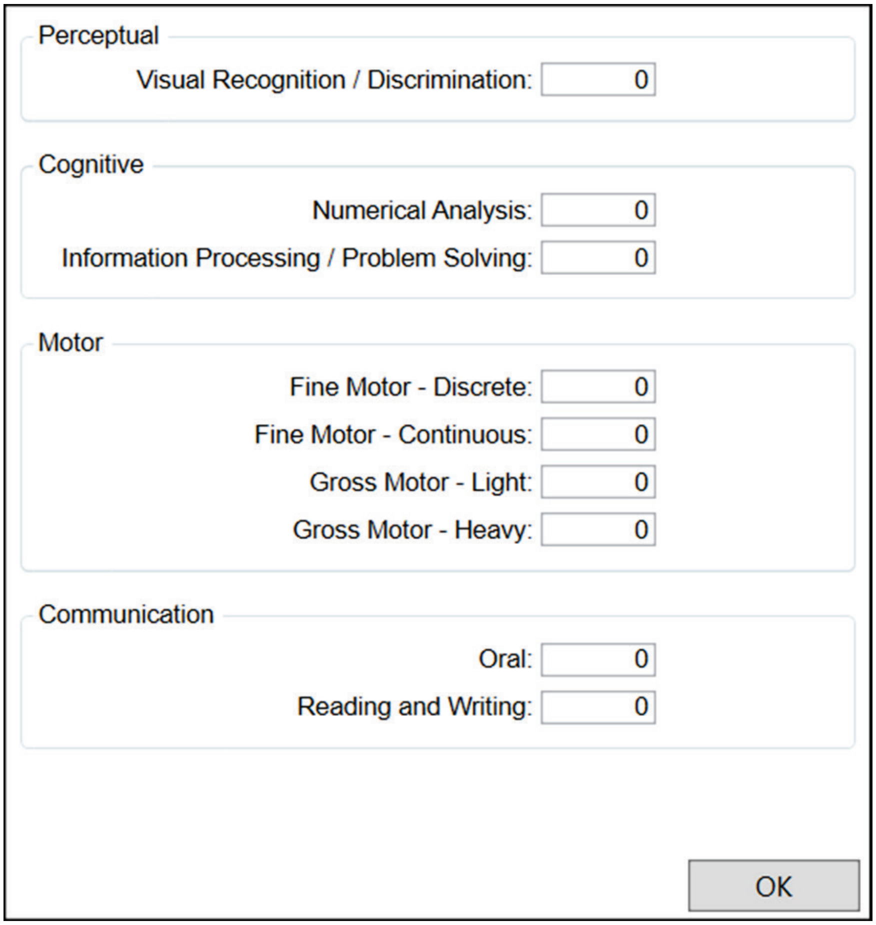


Figure D.20 The *Taxon* weights assignment interface of IMPRINT Pro. *Taxon* weights should add up to 1.0.

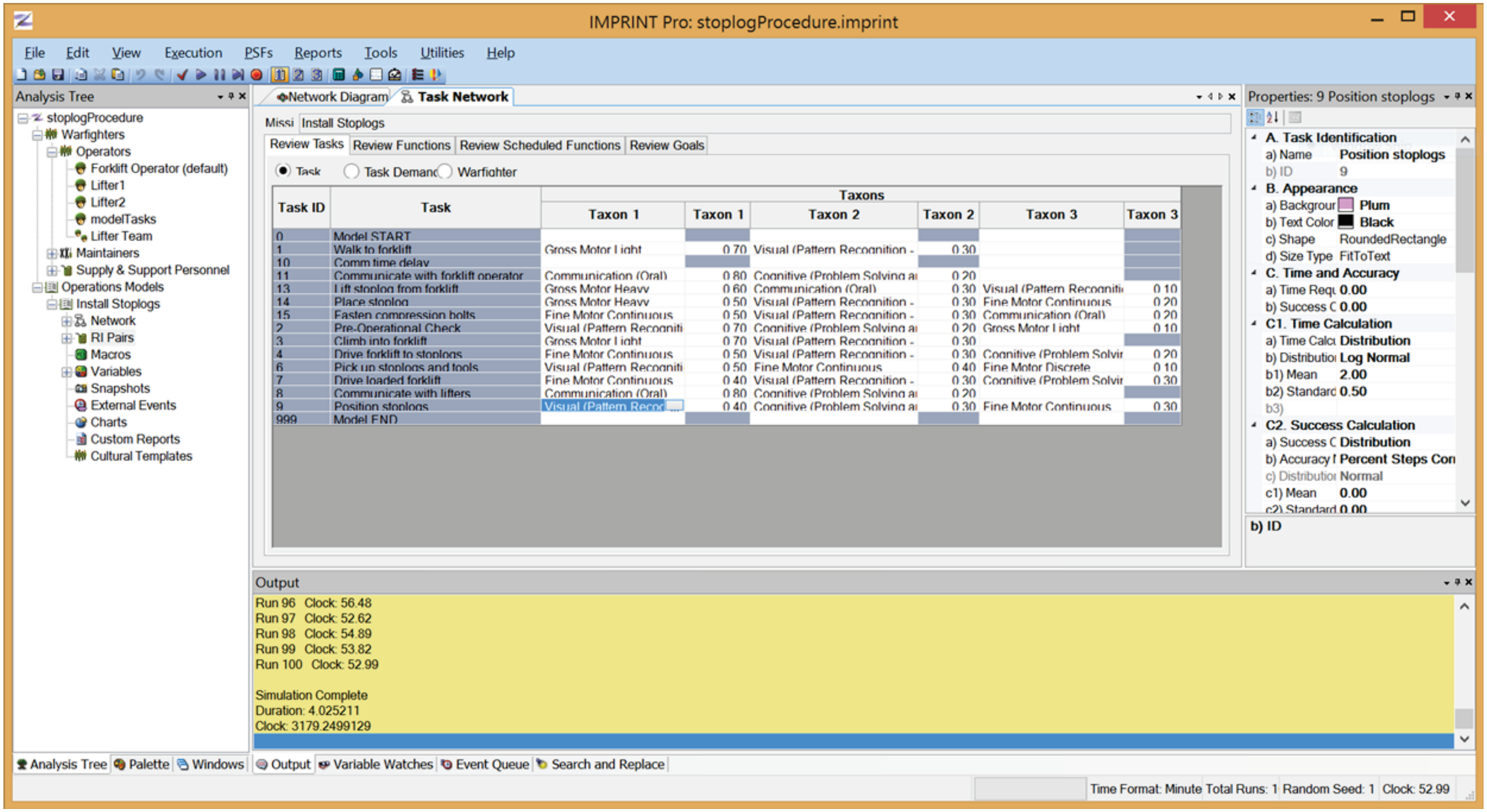


Figure D.21 Final *Taxons* and associated weights assignments for all Tasks of *stoplogProcedure*

IMPRINT
Improved Performance Research Integration Tool

Moderators: Impact of Stressors

(currently modeled in IMPRINT Pro)

Taxon	Heat	Cold	Noise	MOPP	Sleep	WBV	LevelA
Visual	A	T		T		A	TA
Cognitive Numerical	A				TA		
Cognitive Info Processing	A				TA		TA
Fine Motor Discrete	A	T		T		TA	TA
Fine Motor Continuous						TA	
Gross Motor Lt		T		T			
Gross Motor Hvy							
Comm R&W	A						
Comm Oral	A		A	T		A	

T = affects task time, A = affects task accuracy

Figure D.22 ***Stressors*** **currently modeled in IMPRINT Pro (IMPRINT Pro v4.2, Sept. 2016)**

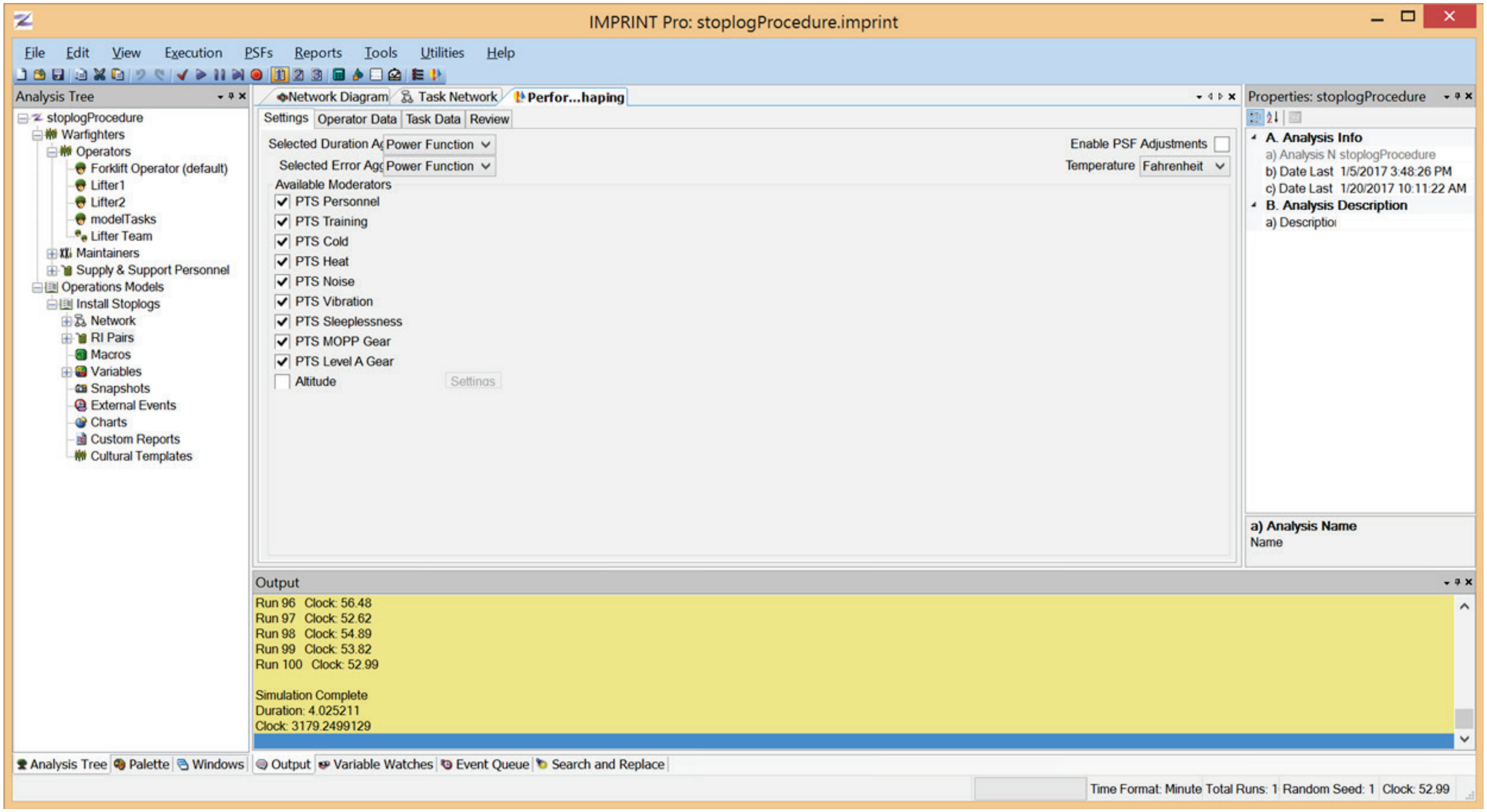


Figure D.23 The *Performance Shaping* tab showing standard *Stressors*

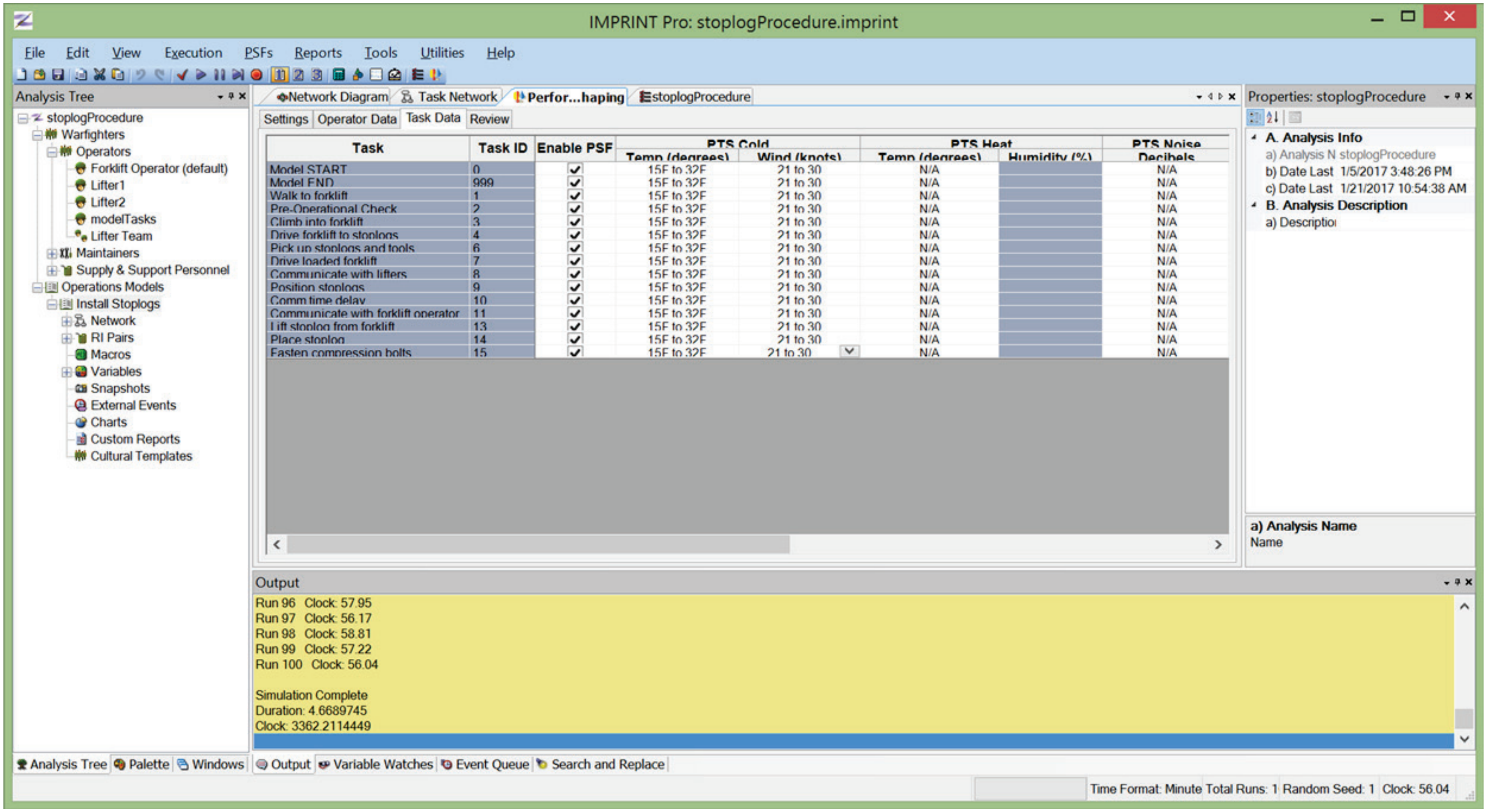


Figure D.24 *PSFs* enabled for all *Tasks* specified as *Cold*. *Cold* was represented as temperatures ranging from 15 to 32°F and wind speeds ranging from 0 to 10 kt.

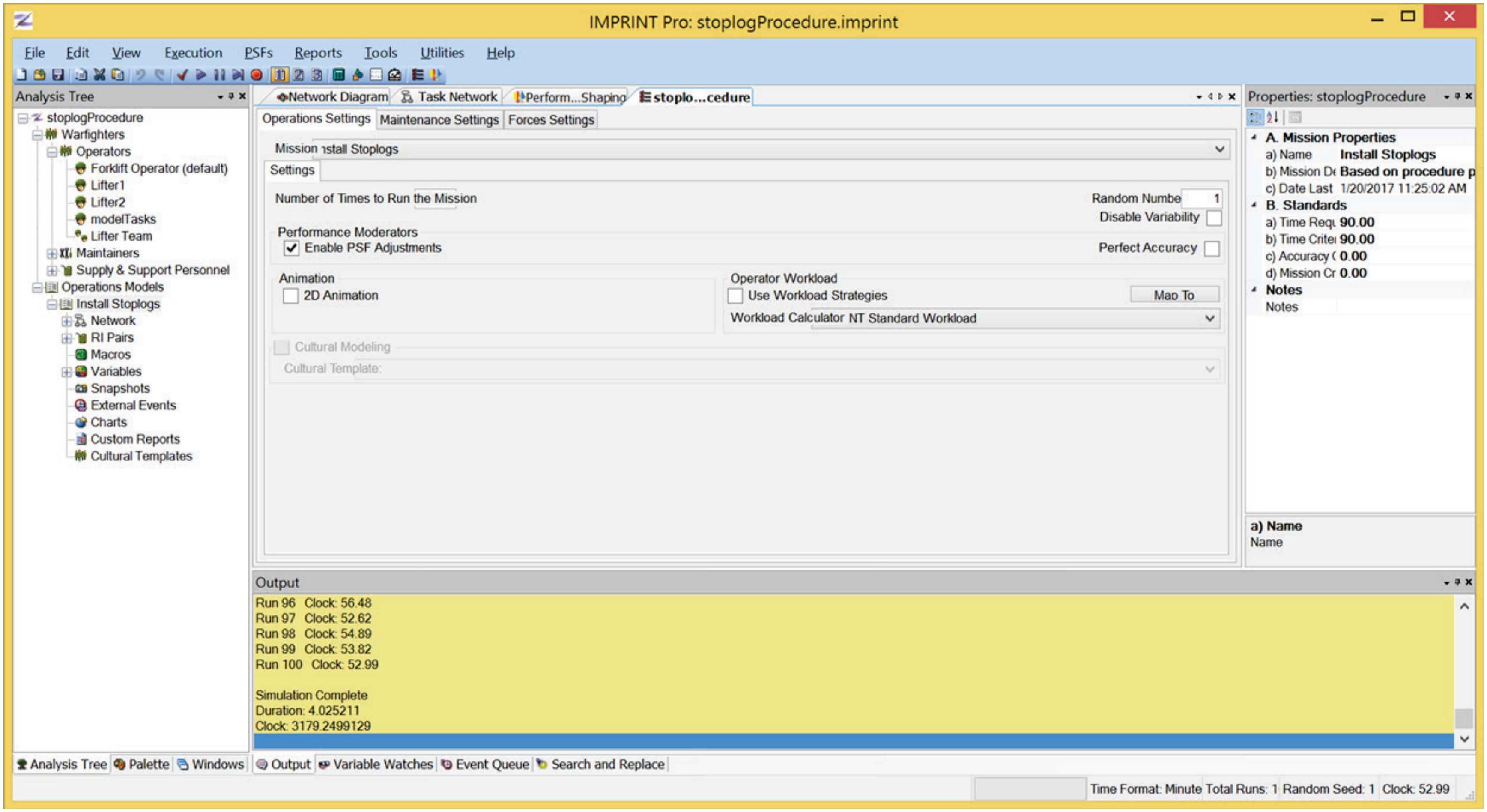


Figure D.25 ***PSF Adjustments*** **enabled on the** ***stoplogProcedure Operator Settings*** **tab**

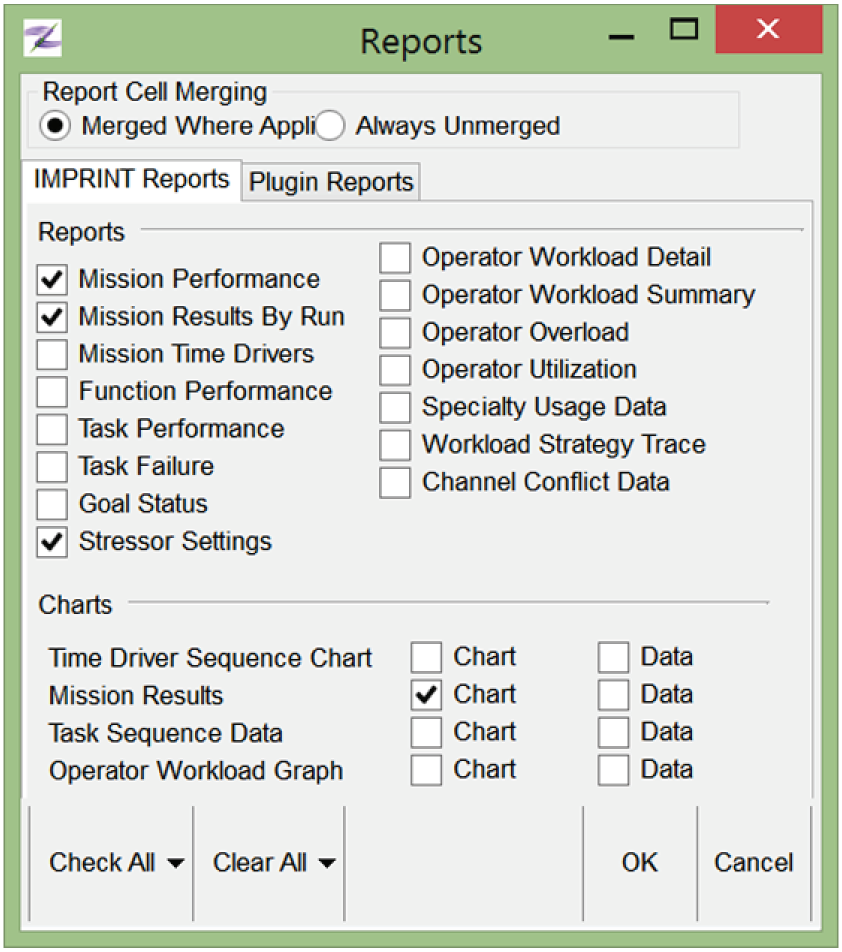
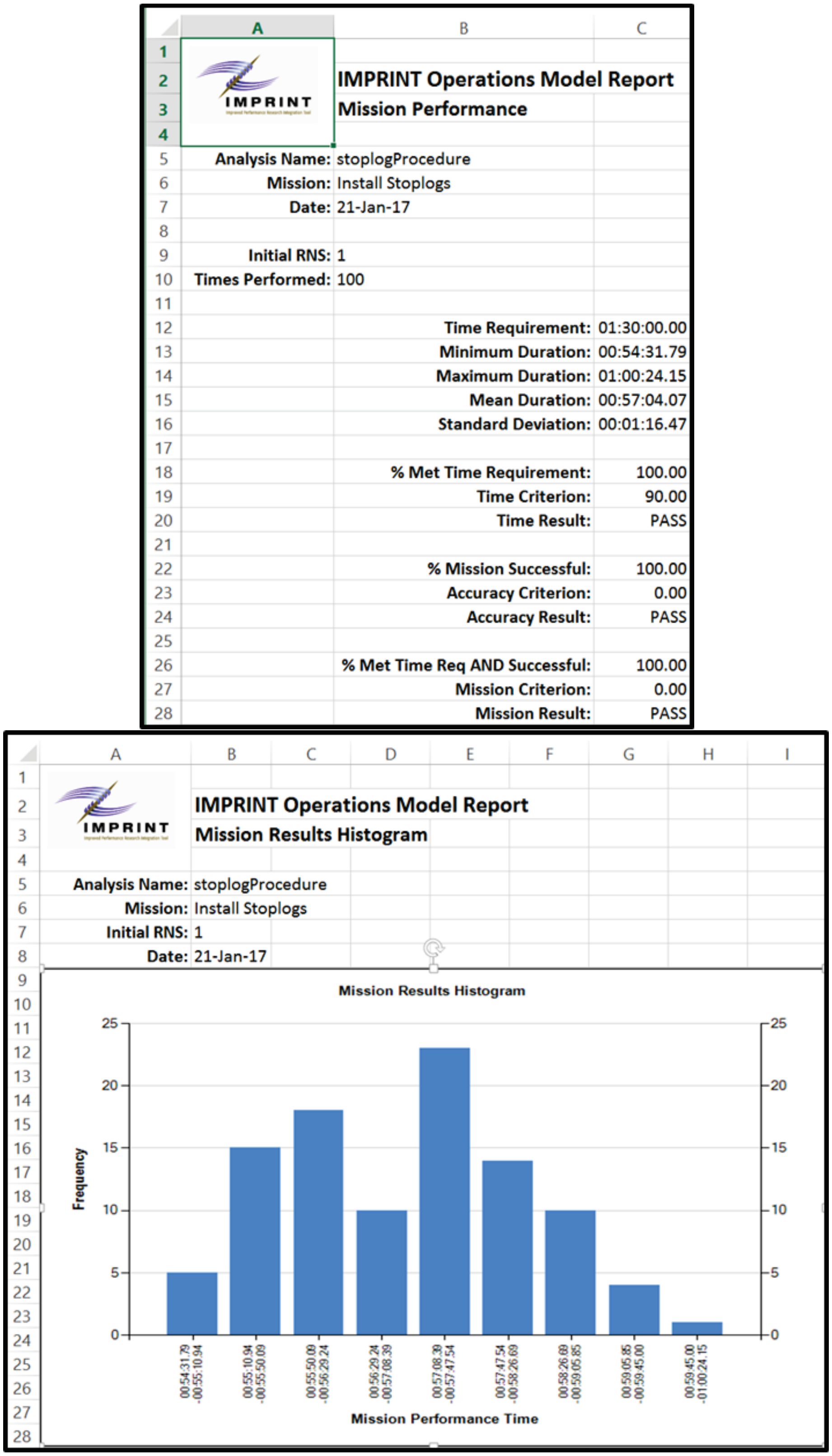


Figure D.26 Items selected for report generation for 100 runs with *PSFs* enabled



	A	B	C
1			
2		IMPRINT Operations Model Report	
3		Mission Performance	
4			
5	Analysis Name:	stoplogProcedure	
6	Mission:	Install Stoplogs	
7	Date:	21-Jan-17	
8			
9	Initial RNS:	1	
10	Times Performed:	100	
11			
12		Time Requirement:	01:30:00.00
13		Minimum Duration:	00:54:31.79
14		Maximum Duration:	01:00:24.15
15		Mean Duration:	00:57:04.07
16		Standard Deviation:	00:01:16.47
17			
18		% Met Time Requirement:	100.00
19		Time Criterion:	90.00
20		Time Result:	PASS
21			
22		% Mission Successful:	100.00
23		Accuracy Criterion:	0.00
24		Accuracy Result:	PASS
25			
26		% Met Time Req AND Successful:	100.00
27		Mission Criterion:	0.00
28		Mission Result:	PASS

Figure D.27 Output from 100 runs of *stoplogProcedure* with *Cold*

D.4.2.2 Adding a Custom Moderator in IMPRINT Pro

To add a new *Custom Moderator* in IMPRINT Pro, the following steps were performed:

- A New Custom Moderator was added by right-clicking the stoplogProcedure analysis in the Analysis Tree and selecting New Moderator → New Custom Moderator. IMPRINT Pro added a new branch to the stoplogProcedure Analysis called Custom Performance Shaping with one element called Custom Moderator (**Figure D.28**). The default name, Custom Moderator, was renamed to WaterDepthXSpeed; this was accomplished by double-clicking the Custom Moderator element in the Custom Performance Shaping branch of the stoplogProcedure Analysis Tree and changing the name in the Custom Moderator tab.
- A *Custom Moderator* in IMPRINT Pro is used to define performance degradation via coefficients for predefined levels of the *Moderator*. Therefore, the trainees added a *Moderator* level called *3ftSquarePerSec* (product of water depth and velocity of 1 ft deep, 3 ft/s flow). For this example assessment, the trainees assumed that the *Moderator* level *3ftSquarePerSec* would result in increased performance time. Increased performance time for a *Task* in IMPRINT Pro manifests via increased performance time for one or more *Taxons*. For this example assessment, and only for purposes of illustration, the trainees assumed that the *WaterDepthXSpeed* level of *3ftSquarePerSec* would result in four-fold increases in *gross motor heavy, gross motor light, fine motor continuous*, and *cognitive Taxons*. To specify the time increase associated with *Taxons*, the trainees provided code *for Time Algorithm* in the *Moderator Code Editor* to multiply *Task* times for *gross motor heavy, gross motor light, fine motor continuous*, and *cognitive Taxons* by 4.0 (**Figure D.29**).
- The new *Custom Moderator* added by the trainees then appeared under the *Performance Shaping* tab in the list of available *Moderators* (**Figure D.30**). The trainees ensured that the checkbox for *WaterDepthXSpeed* was checked to enable the new *Custom Moderator*. Before *WaterDepthXSpeed* can affect *Task* performance, its level must be set in the Task Data table of the Performance Shaping tab (**Figure D.31**). For this example assessment, the trainees selected the *3ftSquarePerSec* level for the *Custom Moderator* to apply to all *Tasks* throughout the *Mission*. Accordingly, the *Tasks* were modeled to be affected by two stressors—*Cold* and *WaterDepthXSpeed*.
- In IMPRINT Pro, several methods are available to combine individual effects of multiple simultaneous *Stressors*. For this example assessment, the trainees used the IMPRINT Pro default method in which a power function is used to combine impacts of individual *Stressors.*
- The *stoplogProcedure* model was run again for 100 simulations with the *Custom Stressor WaterDepthXSpeed* applied at a level of *3ftSquarePerSec* for all *Tasks*. The results showed that the mean *Mission* performance time increased to 3 hr 4 min 9 sec with minimum and maximum *Mission* performance times of 2 hr 55 min 58 sec and 3 hr 17 min 1 sec, respectively (**Figure D.32**). None of the model simulations met the time requirement of 90 minutes. Results showed that the performance time for *Tasks* requiring motor skills increased 3 to 4 times, which is not surprising because the *Custom Moderator*, *WaterDepthXSpeed*, applies a multiplicative factor of 4.0 for motor *Taxons*. The example *Custom Moderator* is perhaps extreme in its effects and the appropriate multipliers for *Task* performance times for *Taxons* should be informed by literature, experiments, and expert opinion.

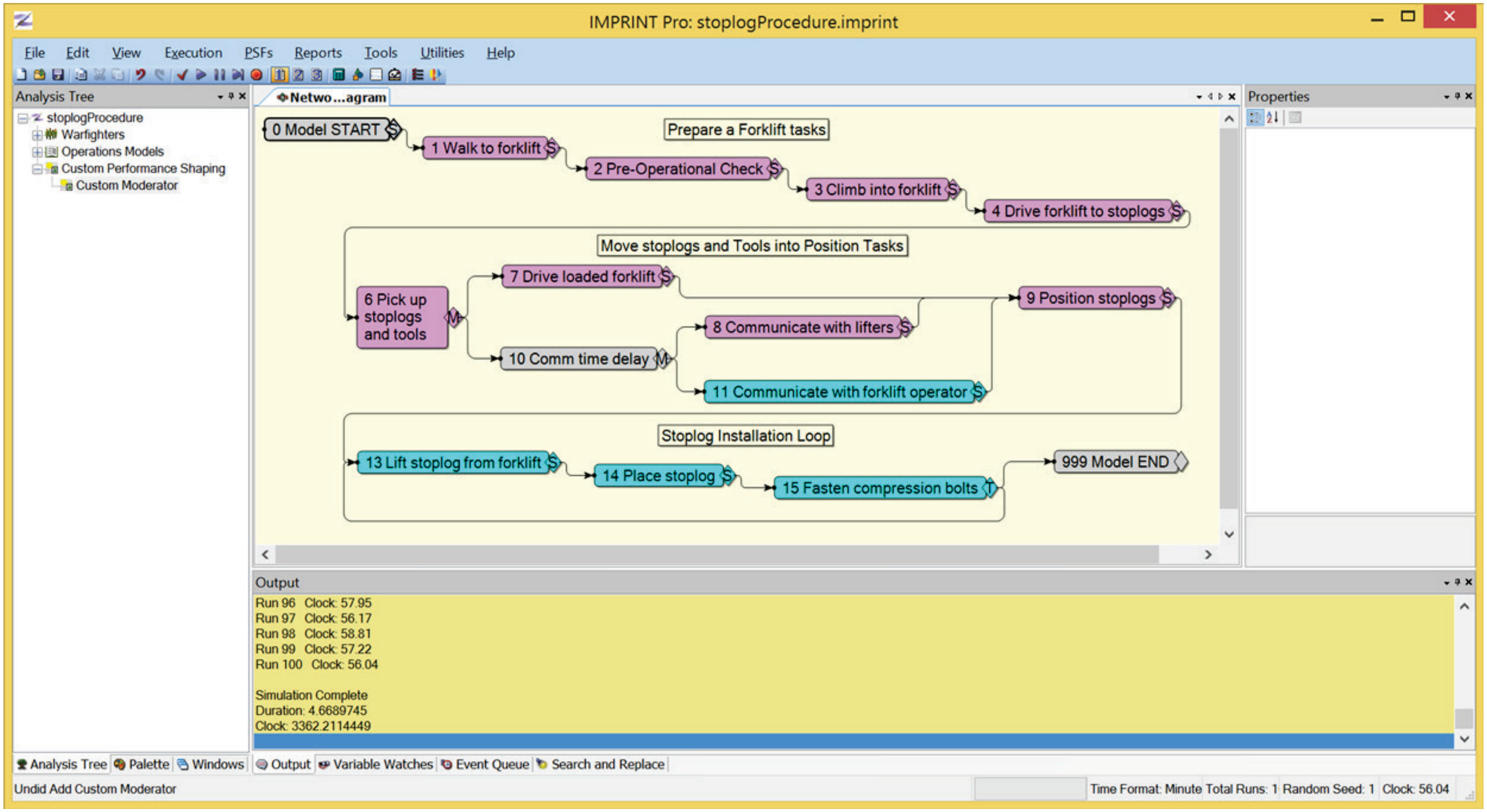


Figure D.28 Adding a new *Custom Moderator* to the *Analysis*

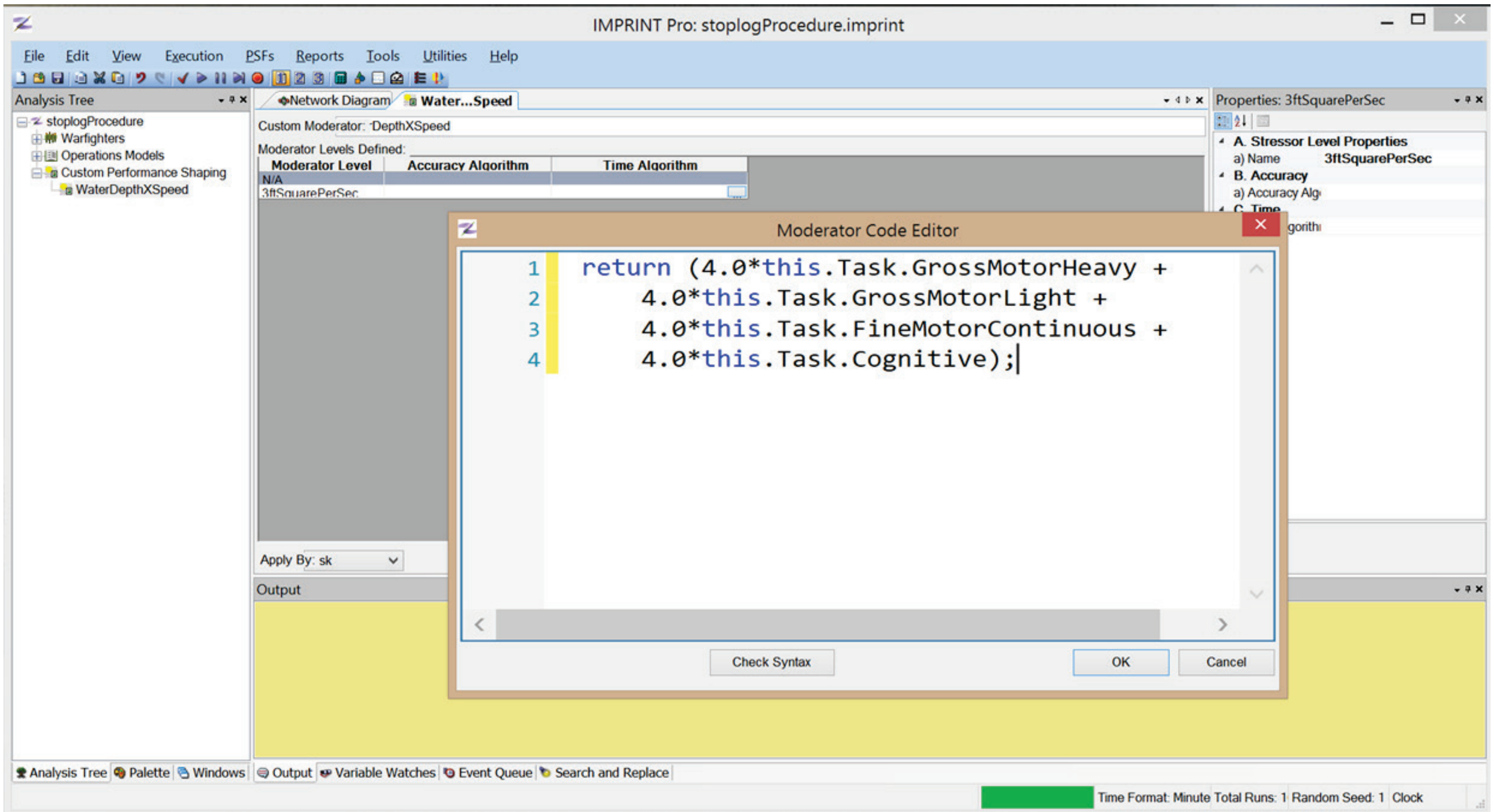


Figure D.29 ***Time Algorithm*** **code for** ***WaterDepthXSpeed Custom Moderator*****'s 3ftSquarePerSec Moderator level**

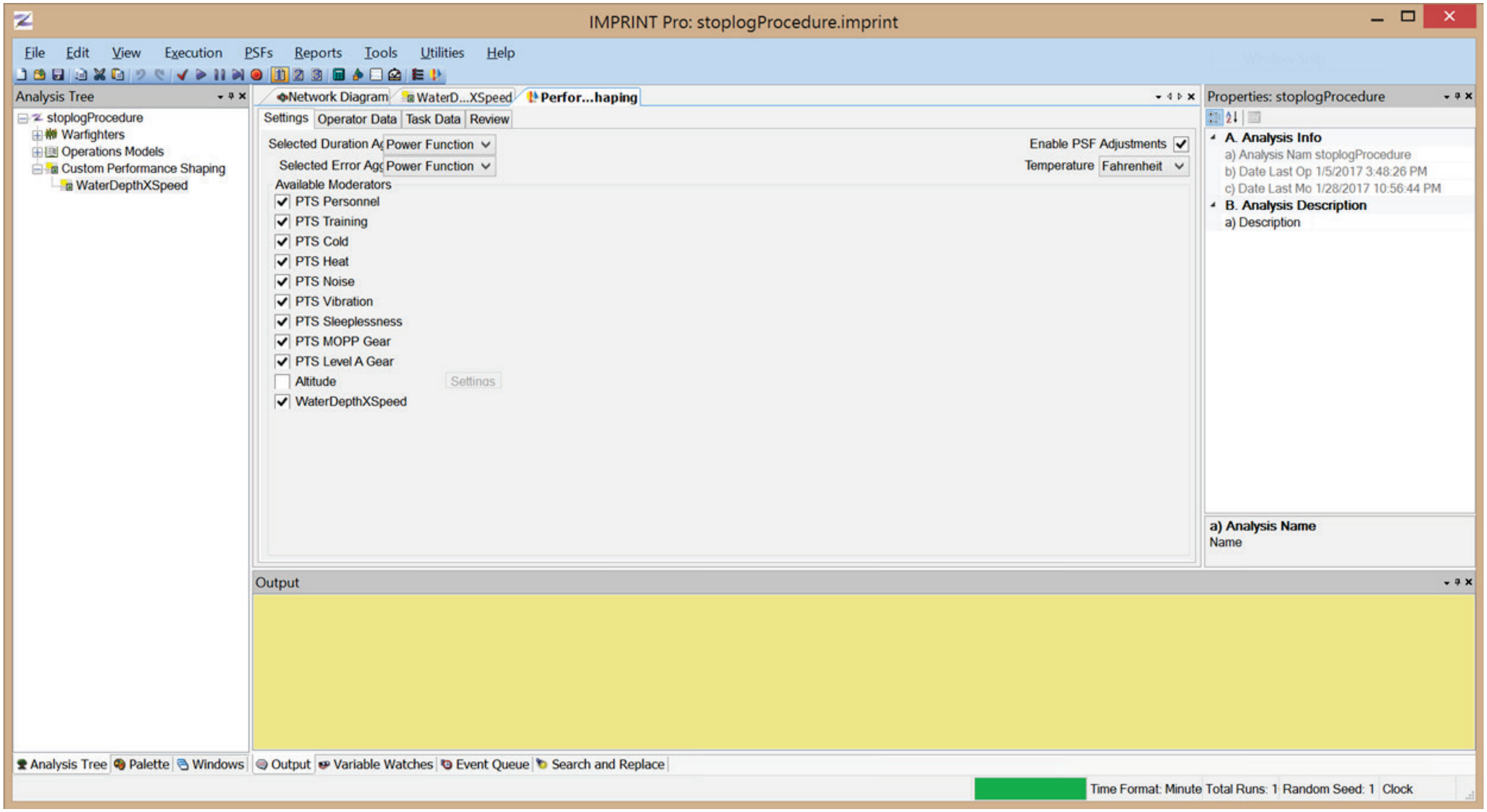


Figure D.30 The new *Custom Moderator*, *WaterDepthXSpeed* shown in the *Performance Shaping* tab

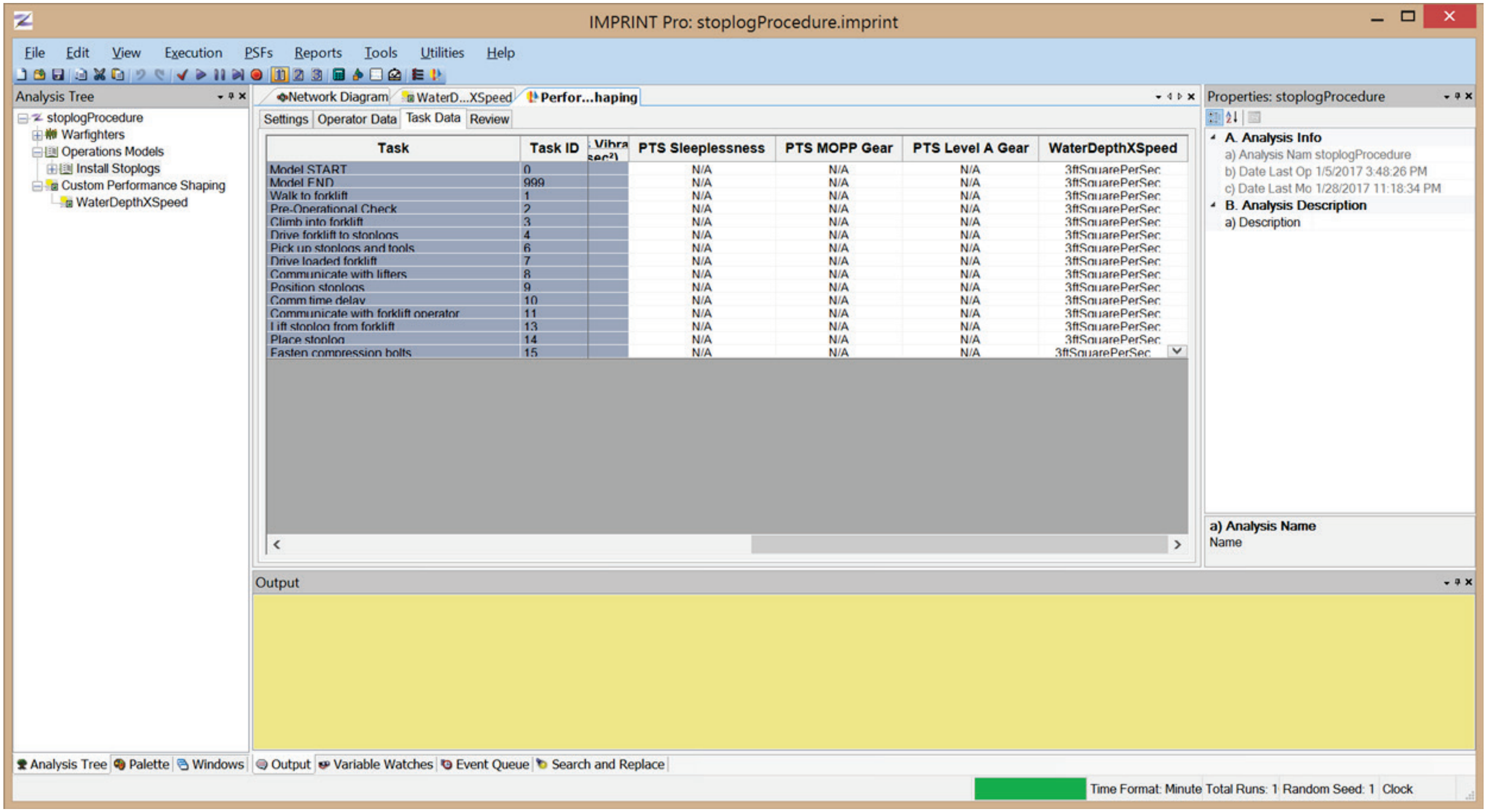
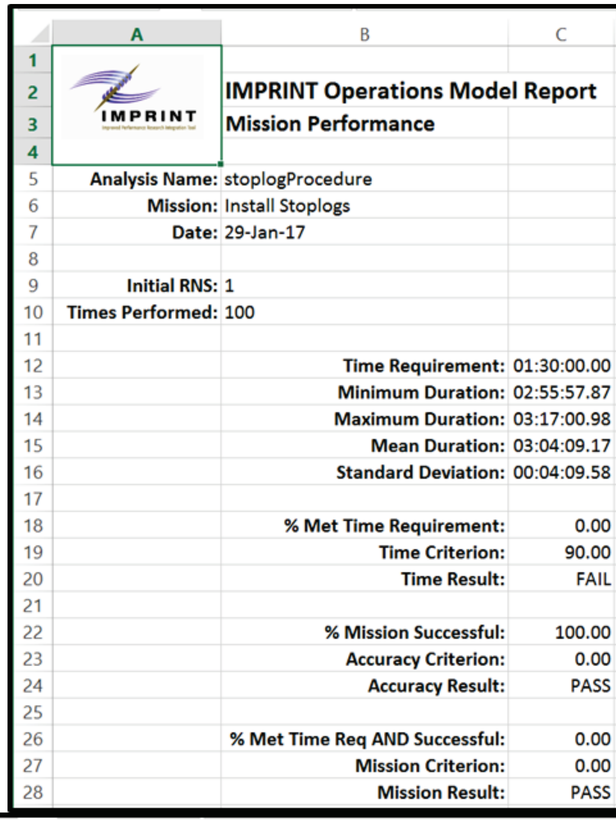


Figure D.31 *WaterDepthXSpeed* applied to all *Tasks* at level *3ftSquarePerSec*



IMPRINT Operations Model Report	
Mission Performance	
Analysis Name:	stoplogProcedure
Mission:	Install Stoplogs
Date:	29-Jan-17
Initial RNS:	1
Times Performed:	100
Time Requirement:	01:30:00.00
Minimum Duration:	02:55:57.87
Maximum Duration:	03:17:00.98
Mean Duration:	03:04:09.17
Standard Deviation:	00:04:09.58
% Met Time Requirement:	0.00
Time Criterion:	90.00
Time Result:	FAIL
% Mission Successful:	100.00
Accuracy Criterion:	0.00
Accuracy Result:	PASS
% Met Time Req AND Successful:	0.00
Mission Criterion:	0.00
Mission Result:	PASS

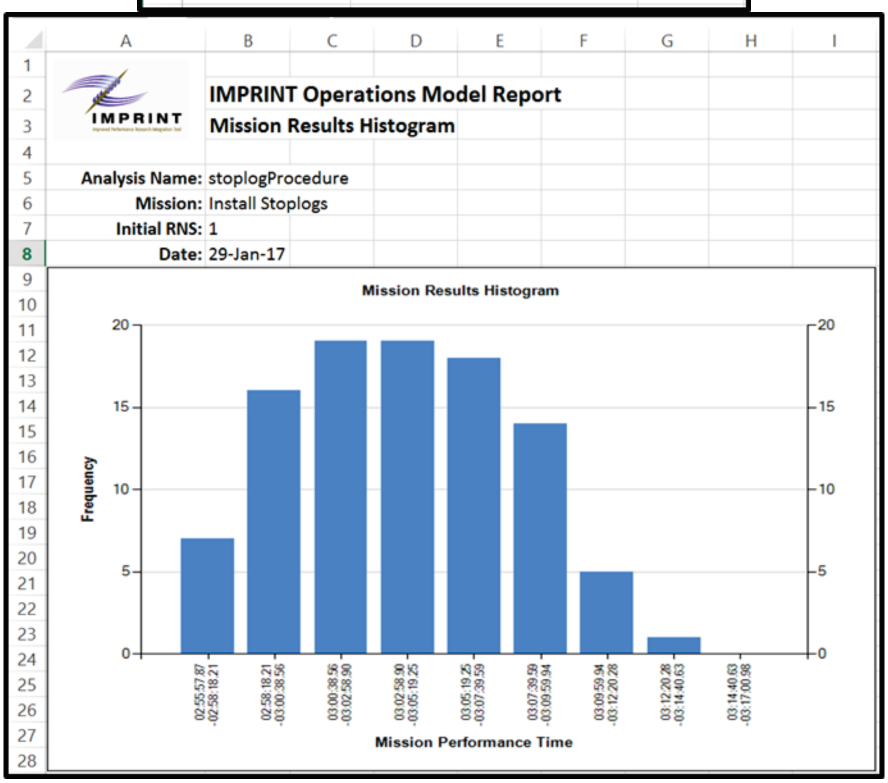


Figure D.32 Results from 100 runs of *stoplogProcedure* with *Cold* and *WaterDepthXSpeed*. *Cold* and *WaterDepthXSpeed* specified as 15–32°F temperatures and 21–30 kt winds; 1 ft deep and 3 ft/s.

D.4.2.3 Adding a Moderator Using Plug-ins in IMPRINT Pro

Alion provided a sample plug-in code that implemented the effects of altitude for an example demonstration. The trainees were able to compile the code (programmed in C#) using Microsoft Visual Studio Pro 2015. Upon successful compilation, the Altitude plug-in created a dynamically linked library (DLL). The DLL was then copied to the IMPRINT Pro installation folder. The trainees restarted IMPRINT Pro and loaded the *stoplogProcedure Analysis*. The *Altitude* DLL was recognized by IMPRINT Pro and appeared as a selectable option in the *Performance Shaping* tab (**Figure D.33**). The Altitude plug-in was selected under the Performance Shaping tab to make it available to *stoplogProcedure Analysis;* this step enabled the Settings button for the plug-in. The *Altitude* plug-in, as coded, had one user-adjustable setting—the *Sleeping Elevation*, set to a default of 10,000 ft (**Figure D.34**).IMPRINT Pro, several methods are available to combine individual effects of multiple simultaneous *Stressors*. For this example assessment, the trainees used the IMPRINT Pro default method in which a power function is used to combine impacts of individual *Stressors.*

The *stoplogProcedure* model was run again for 100 simulations with the *Custom Stressor WaterDepthXSpeed* applied at a level of *3ftSquarePerSec* for all *Tasks*. The results showed that the mean *Mission* performance time increased to 3 hr 4 min 9 sec with minimum and maximum *Mission* performance times of 2 hr 55 min 58 sec and 3 hr 17 min 1 sec, respectively (**Figure D.32**). None of the model simulations met the time requirement of 90 minutes. Results showed that the performance time for *Tasks* requiring motor skills increased 3 to 4 times, which is not surprising because the *Custom Moderator*, *WaterDepthXSpeed*, applies a multiplicative factor of 4.0 for motor *Taxons*. The example *Custom Moderator* is perhaps extreme in its effects and the appropriate multipliers for *Task* performance times for *Taxons* should be informed by literature, experiments, and expert opinion.

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The second place where settings for the *Altitude* plug-in were available was the *Performance Shaping* tab of individual *Tasks* (**Figure D.35**). The settings at the *Task*-level allowed for specification of the elevation at which the *Task* was performed and the levels for the three new *Taxons* called *Perception, Salience*, and *Vigilance*. Each of the three new *Taxons* could be turned off *(None)* or set to one of three levels (*Low, Medium,* and *High*). The Alion staff noted that the new *Taxons* coded in the *Altitude* plug-in would be available to the *Analysis* in addition to those already available in IMPRINT Pro. The third place where settings for the *Altitude* plug-in were available was at the Operator level, where the *Susceptibility of Altitude* for a selected *Operator* could be set (**Figure D.36**).

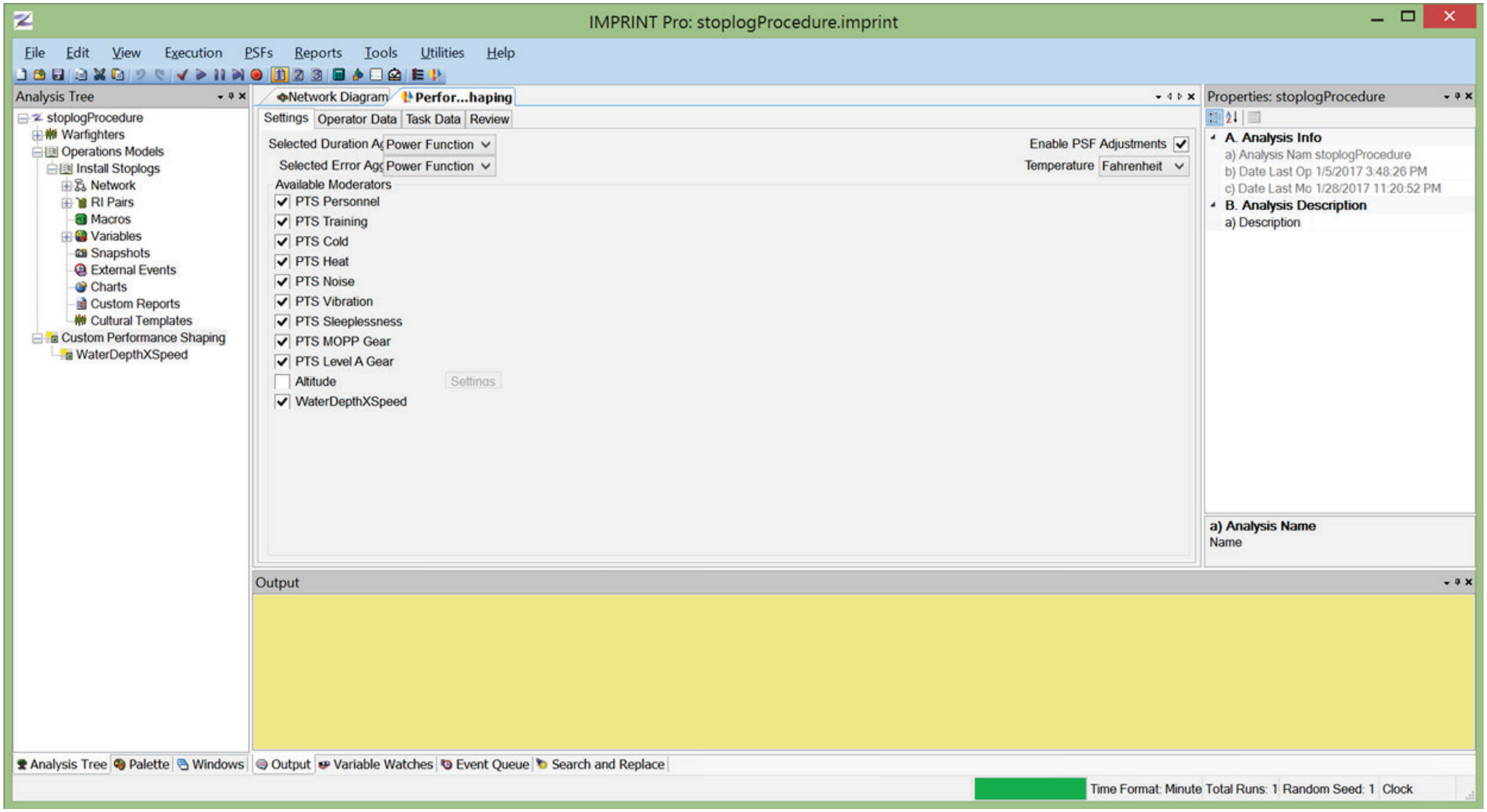

Figure D.33 Plug-in *Altitude* available in IMPRINT Pro

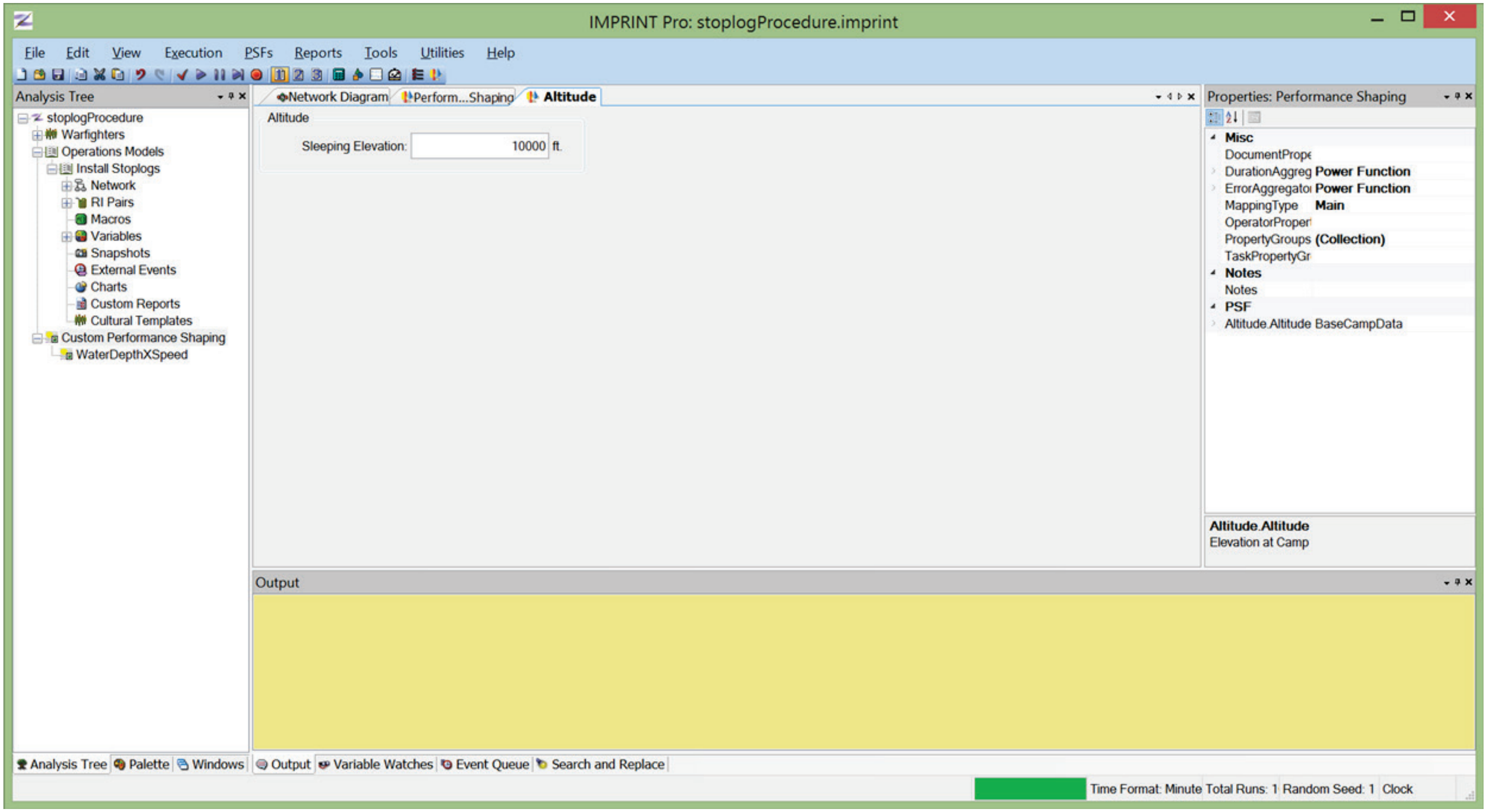

Figure D.34 The *Altitude* tab in IMPRINT Pro showing user-adjustable settings

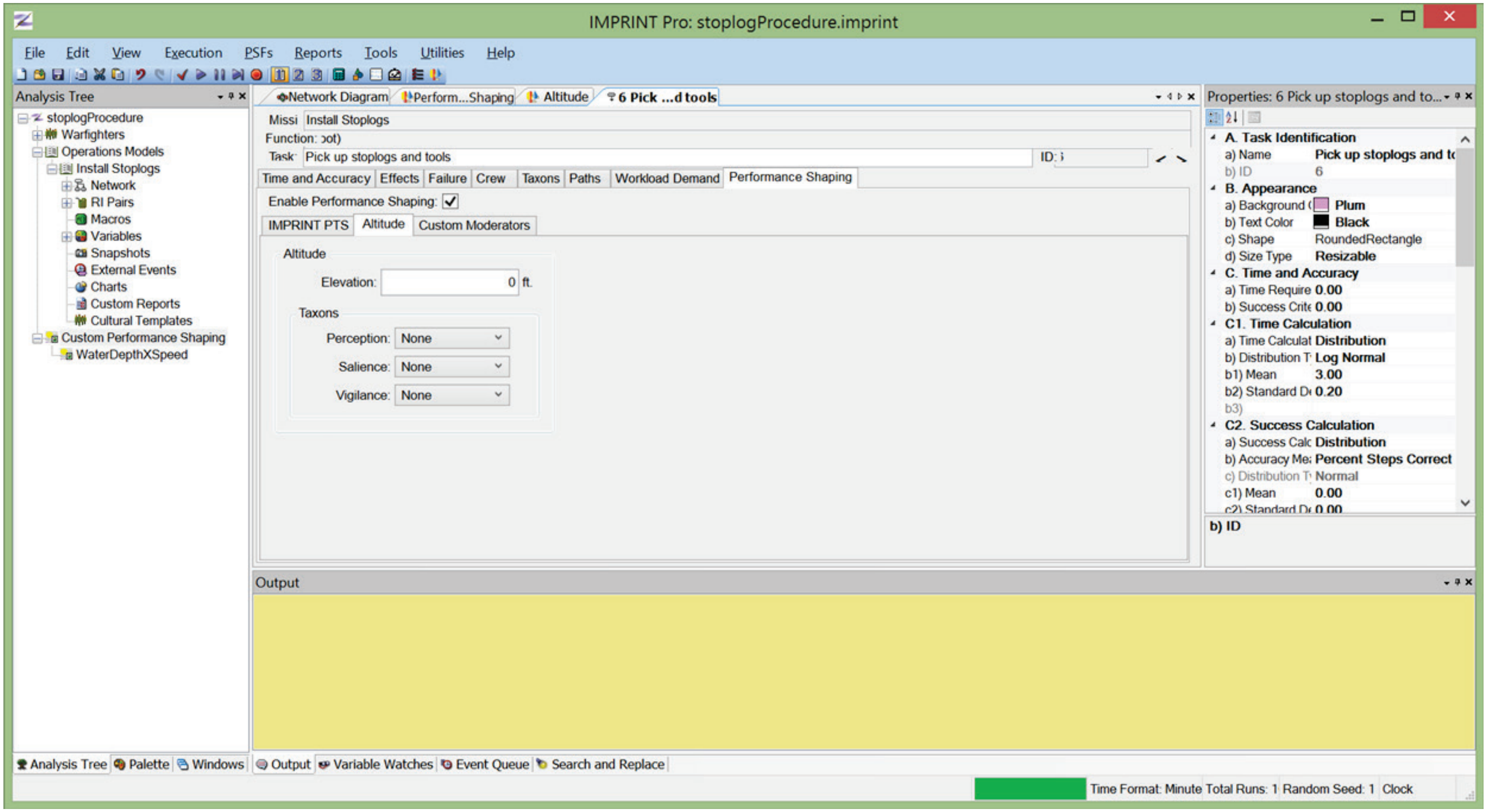

Figure D.35 Additional settings for *Altitude* can be selected in an individual *Tasks' Performance Shaping* tab

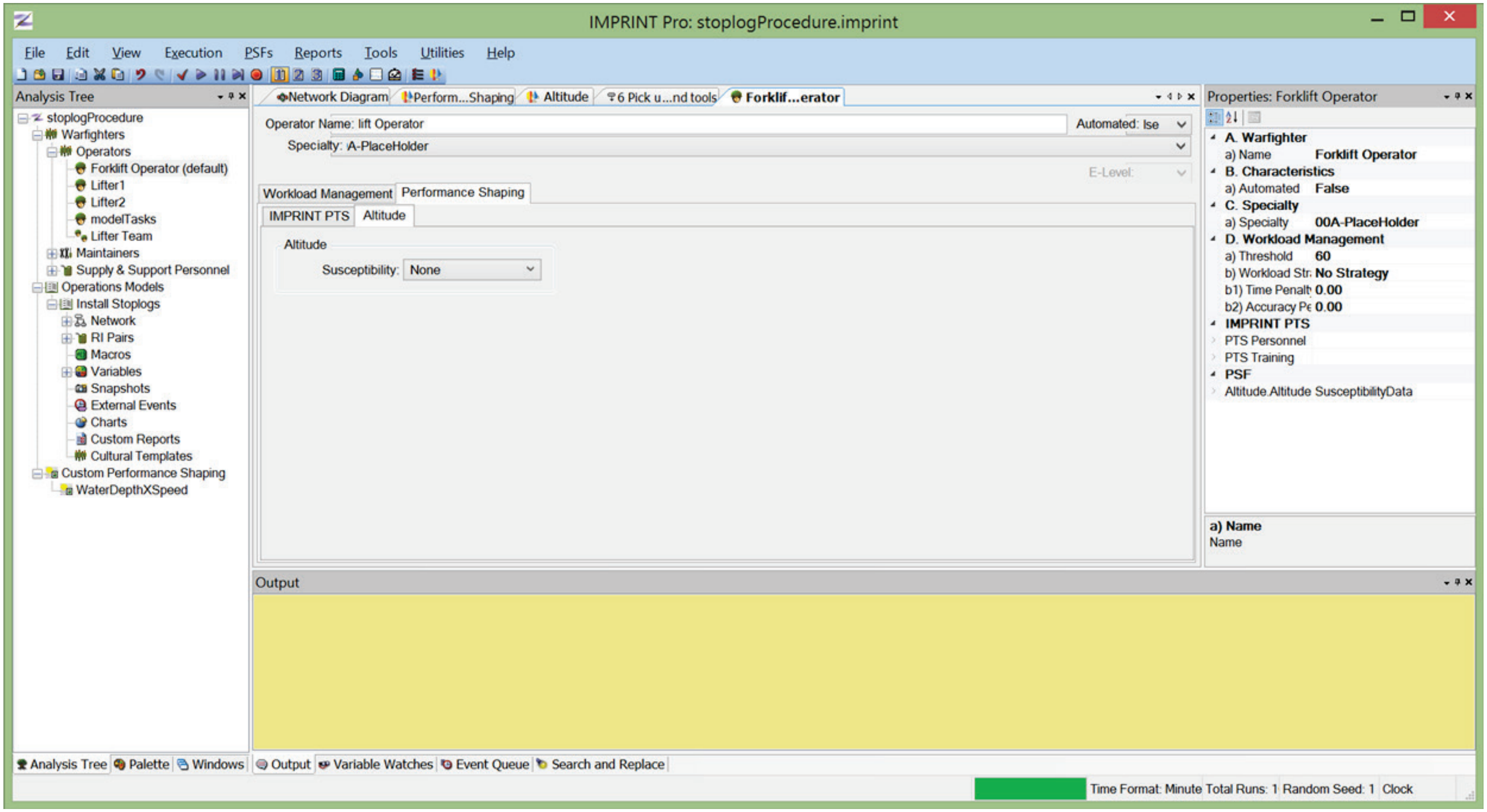

Figure D.36 ***Operator*-level settings for Altitude**

The Alion staff noted that the plug-in was intended only as a demonstration of how new functionality, both new *Moderators* and new *Taxons*, could be added to IMPRINT Pro. Alion staff described the coding needed for the *Altitude* plug-in. The following is a list of program files implementing the *Altitude* plug in and their contents:

1. Provider.cs:
   a. namespace declaration
   b. namespace aliases, and
   c. namespace references
2. AltitudeStressor.cs:
   a. editor types for baseline elevation, task-level settings, and operator-level settings
   b. code for generating reports
   c. code for calculation of effects
3. TaskTaxons.cs:
   a. definitions of the three new *taxons*
4. TaskData.cs:
   a. definition of task-level data (*Elevation* where *task* is performed)
5. BaseCampData.cs:
   a. definition of baseline tas*k* data (Sleeping *Elevation*)
6. HiMedLo.cs:
   a. definition of the levels (High, Medium, and Low) for taxons
7. SusceptibilityData.cs:
   a. definition of the operator-level data (operator *Susceptibility*)

IMPRINT Pro documentation includes some information related to development of user plug-ins.

D.4.2.5 Task Accuracy and Failure Probability in IMPRINT Pro

In IMPRINT Pro, the probability of meeting an *Accuracy Requirement* for a *Task* can be calculated based on (1) a user-specified probability distribution of accuracy, (2) specifying *Task* success probability and the consequences of failure of the Task (e.g., degradation in *Task* performance time or accuracy, creation of new requirements for another *Task, Task repetition*, and *Mission* failure), and (3) using an expression based on *Task* parameters.

This functionality was demonstrated by assuming that the *Fasten compression bolts Task* could sometimes fail (e.g., *Task* performance complications arising from dropping a tool in flowing water). The effect of a failure in the *Fasten compression bolts Task* was assumed to either result in repetition of the *Task* or the need for recovery *Task*. A new Boolean variable, *inFlowingWater*, and an integer variable, *probFastenSuccess*, were added to the *stoplogProcedure Analysis* (**Figure D.37** and **Figure D.38**). The variable *inFlowingWater* was set to true in the *Beginning Effect* function call for the first real *Task* in the analysis, *Walk to Forklift* (**Figure D.39**). The accuracy of the *Fasten compression bolts Task* was set using *Calculate Task Success* function call (**Figure D.40**). To simulate recovery from failure of *Fasten compression bolts Task*, a new *Task*, *Long recovery task for losing bolt or too*l, was added to the *Task network* (**Figure D.41**) with *Task* times represented with a Gamma distribution of mean

10 min and standard deviation 2 min. It was also assumed that when a failure of *Fasten compression bolts Task* occurs, 50 percent of the time the *Task* would be repeated and 50 percent of the time the recovery *Task* would be needed[1].

The *stoplogProcedure Analysis* was run 100 times for the baseline scenario (recovery *Task* implemented but no *PSFs* applied). The minimum, maximum, and mean baseline times were 53 min 12 sec, 3 hr 40 min 56 sec, and 1 hr 49 min 47 sec, respectively (**Figure D.41**). The baseline times for the 100 simulations only met the time requirement criterion of 1 hr 30 min 29 percent of the time (**Figure D.41**). The distribution of simulated baseline times is also shown.

The *stoplogPrecedure Analysis* was run 100 times applying the *PSFs* (*Cold* with temperatures between 15 and 32°F and wind speeds ranged from 21 to 30 kt and flowing water with 1 ft depth and 3 ft/s speed). The minimum, maximum, and mean affected times were 1 hr 43 min 24 sec, 6 hr 22 min 44 sec, and 3 hr 40 min 23 sec, respectively (**Figure D.42**). The affected times for the 100 simulations did not meet the time requirement criterion of 1 hr 30 min at all. The distribution of the simulated affected times is also shown. With the *PSFs* applied, the mean performance time increased by 1 hr 50 min 36 sec, an increase of nearly 101 percent over the baseline.

The trainees noted that the impacts on *Task* performance time from the effects of *Stressors* was relatively small compared to the time required to repeat or recover failed *Tasks*. This possibility may be an important consideration when assessing the impacts of ECs on certain FPM procedural tasks. Failures could make complicated or difficult tasks problematic to complete under prevailing ECs. This observation could be used with other insights to set up and prioritize resources for analyses of MAs. Different approaches may work better for different MAs. For example, it may be better to assess MAs that are especially prone to failure from limited available time to complete the action using a *Task* time opposed to *Task* accuracy approach. Whereas, MAs with elevated failure rates or those with relatively long-duration recovery times (given a failure occurs) might be better assessed using a *Task* accuracy approach.

[1] After building in the recovery *Task*, *Long recovery task for losing bolt or tool*, the trainees discovered that the model was inconsistent in its logic for where to increment the *counterStoplogInstall* counter to count the number of stoplogs installed. At this point, the code for incrementing *counterStoplogInstall* was moved from the *Ending Effect* function call of the *Fasten compression bolts Task* to the *Ending Effect* function call of *Place stoplog Task*.

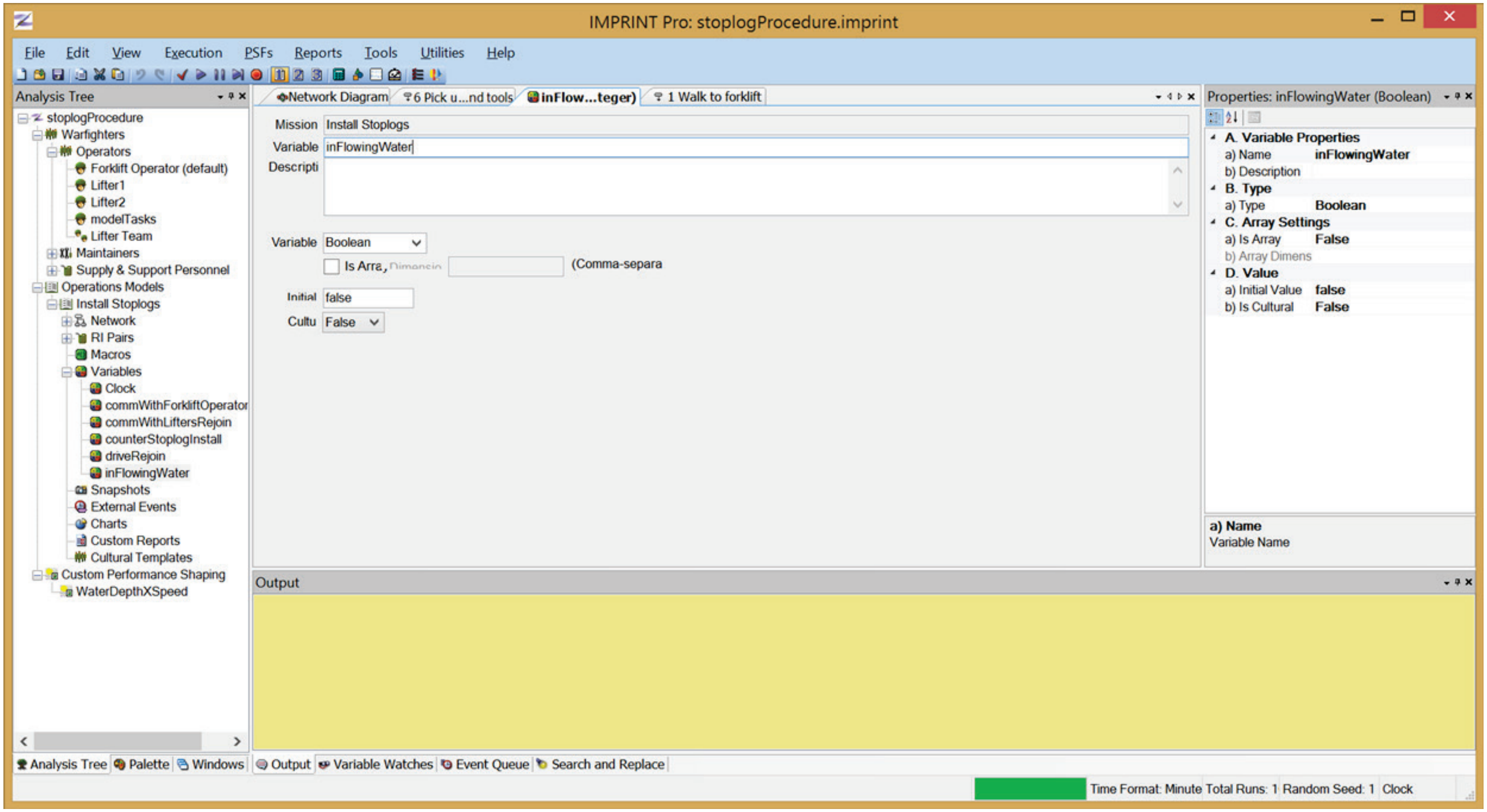

Figure D.37 New Boolean variable *inFlowingWater*

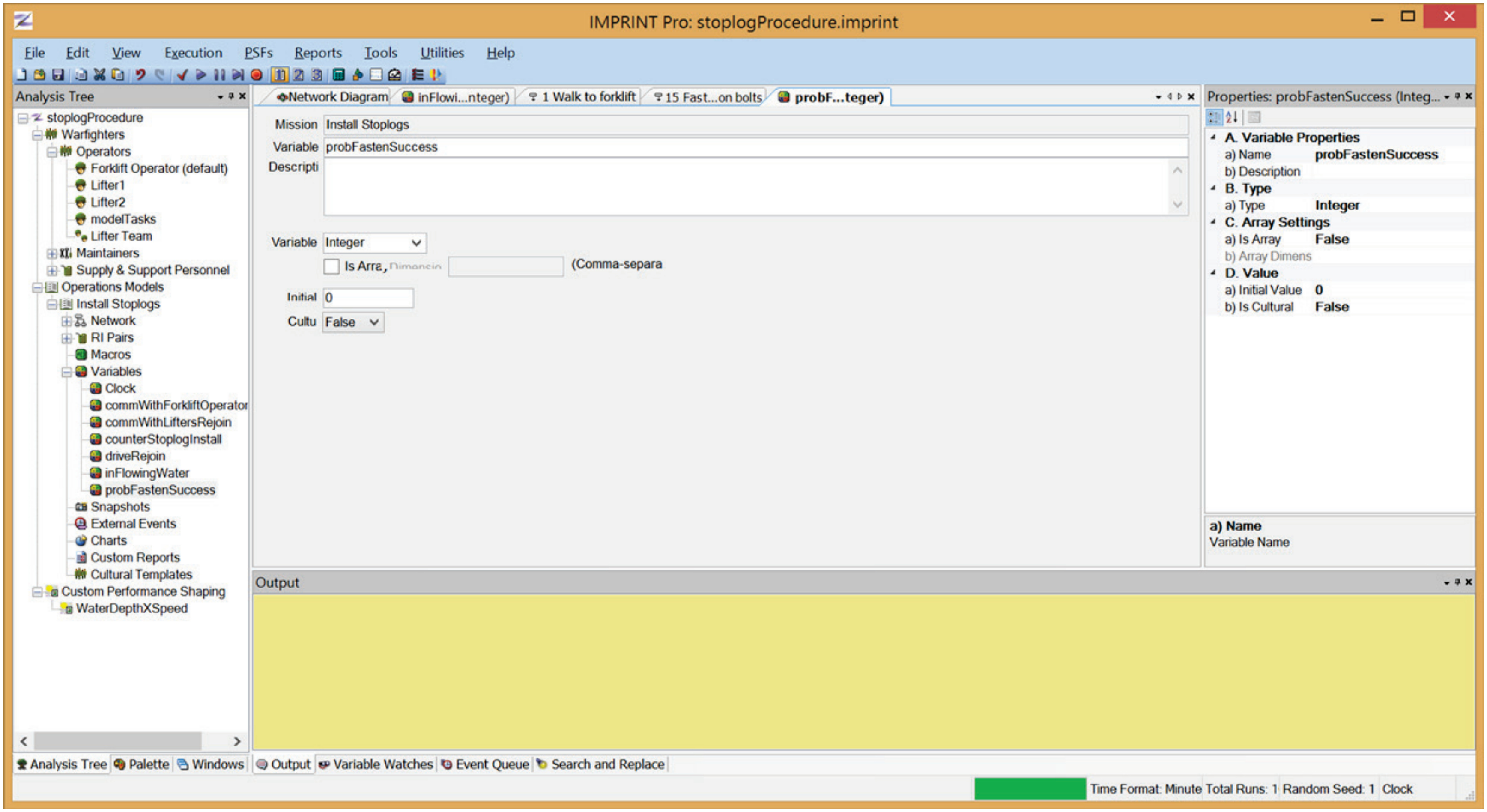

Figure D.38 New integer variable *probFastenSuccess*

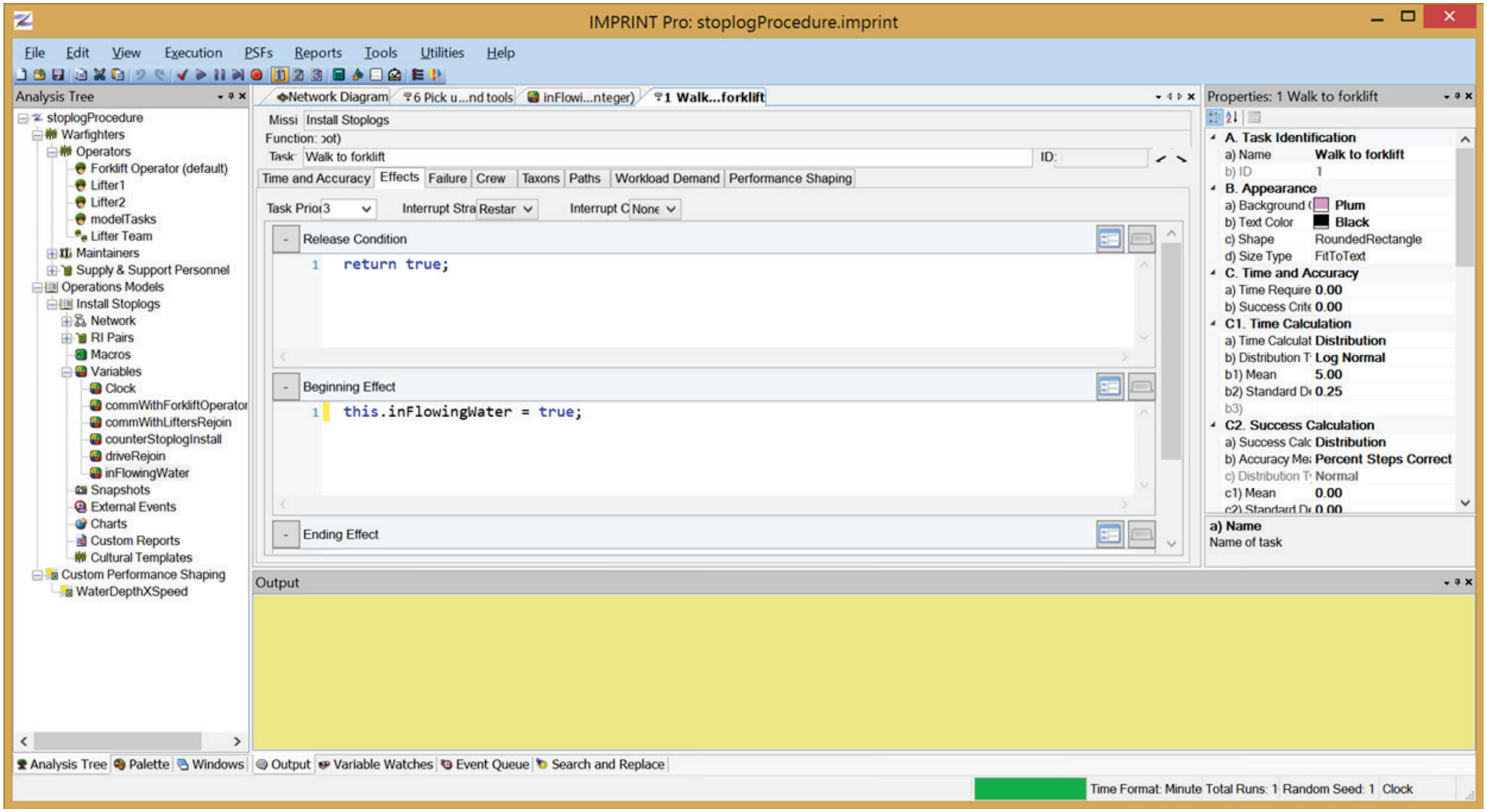

Figure D.39 Setting inFlowingWater to true in *Beginning Effects* code of *Walk to forklift*

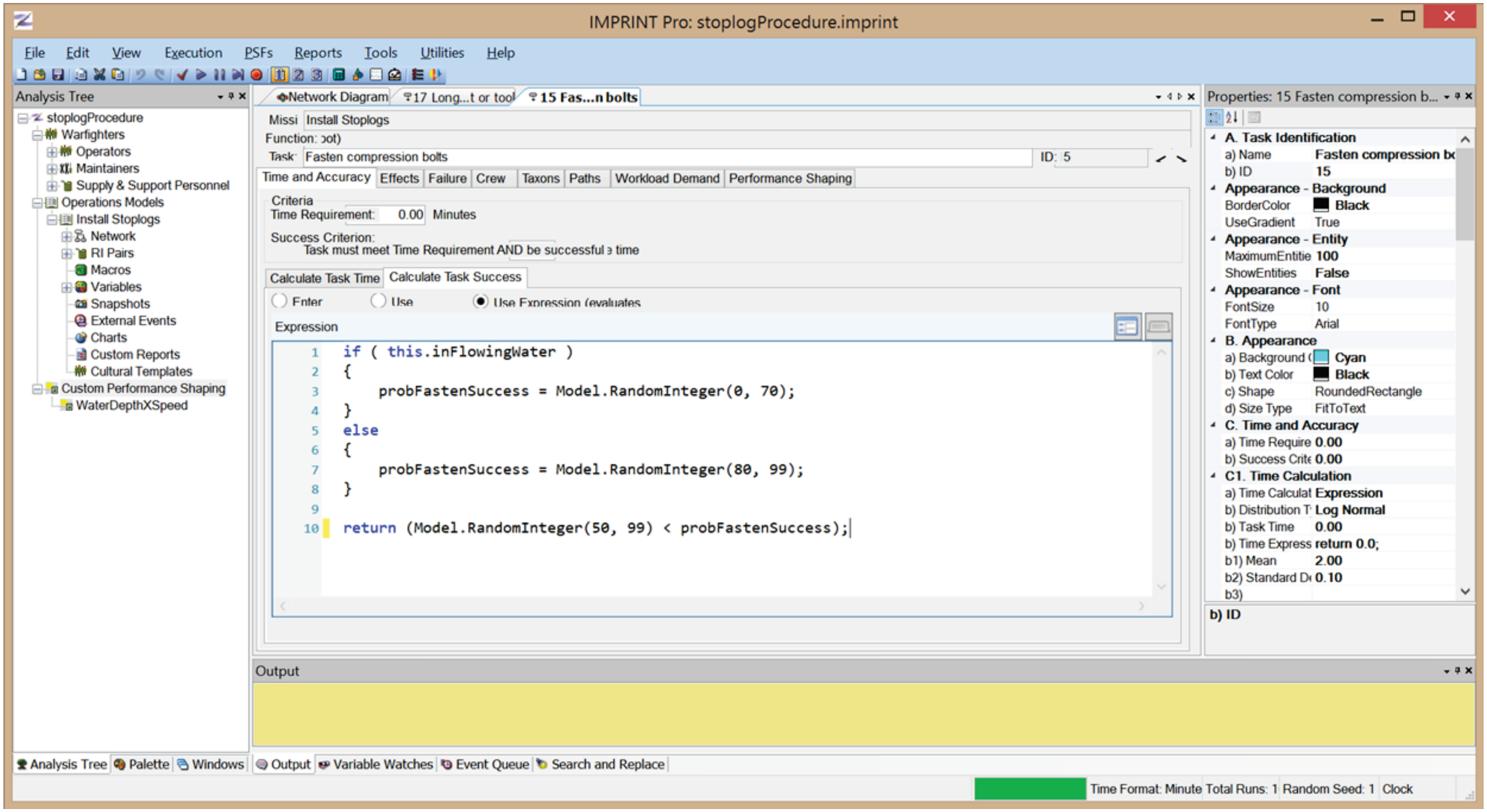

Figure D.40 The *Calculate Task Success* function for *Fasten compression bolts Task*

IMPRINT Operations Model Report
Mission Performance

Analysis Name:	stoplogProcedure
Mission:	Install Stoplogs
Date:	10-Feb-17
Initial RNS:	1
Times Performed:	100

Time Requirement:	01:30:00.00
Minimum Duration:	00:53:12.15
Maximum Duration:	03:40:55.91
Mean Duration:	01:49:47.32
Standard Deviation:	00:33:09.61
% Met Time Requirement:	29.00
Time Criterion:	90.00
Time Result:	FAIL
% Mission Successful:	100.00
Accuracy Criterion:	0.00
Accuracy Result:	PASS
% Met Time Req AND Successful:	29.00
Mission Criterion:	0.00
Mission Result:	PASS

IMPRINT Operations Model Report
Mission Results Histogram

Analysis Name:	stoplogProcedure
Mission:	Install Stoplogs
Initial RNS:	1
Date:	10-Feb-17

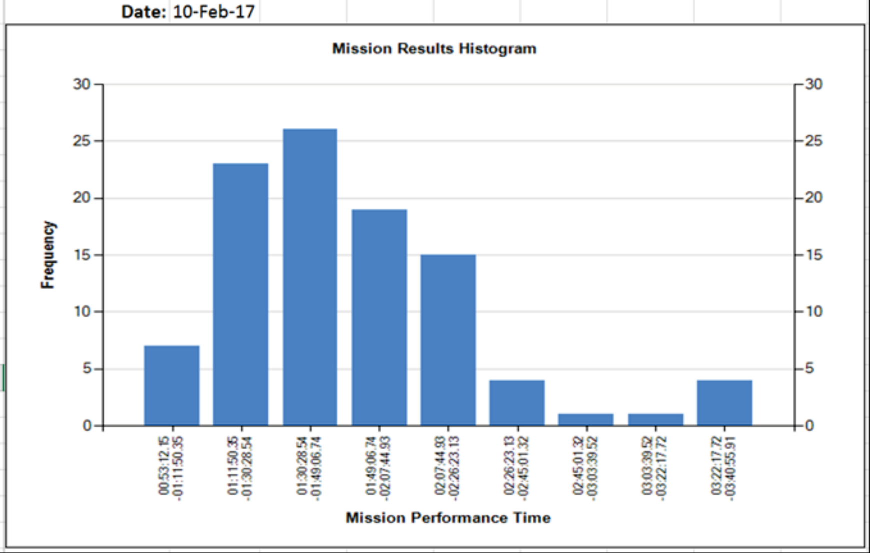

Figure D.41 Output from 100 runs of *stoplogProcedure* with recovery from losing bolts (no *PSFs* applied). Baseline times shown.

IMPRINT Operations Model Report
Mission Performance

Analysis Name:	stoplogProcedure
Mission:	Install Stoplogs
Date:	10-Feb-17
Initial RNS:	1
Times Performed:	100

Time Requirement:	01:30:00.00
Minimum Duration:	01:43:23.58
Maximum Duration:	06:22:44.36
Mean Duration:	03:40:22.55
Standard Deviation:	00:59:50.55
% Met Time Requirement:	0.00
Time Criterion:	90.00
Time Result:	FAIL
% Mission Successful:	100.00
Accuracy Criterion:	0.00
Accuracy Result:	PASS
% Met Time Req AND Successful:	0.00
Mission Criterion:	0.00
Mission Result:	PASS

IMPRINT Operations Model Report
Mission Results Histogram

Analysis Name:	stoplogProcedure
Mission:	Install Stoplogs
Initial RNS:	1
Date:	10-Feb-17

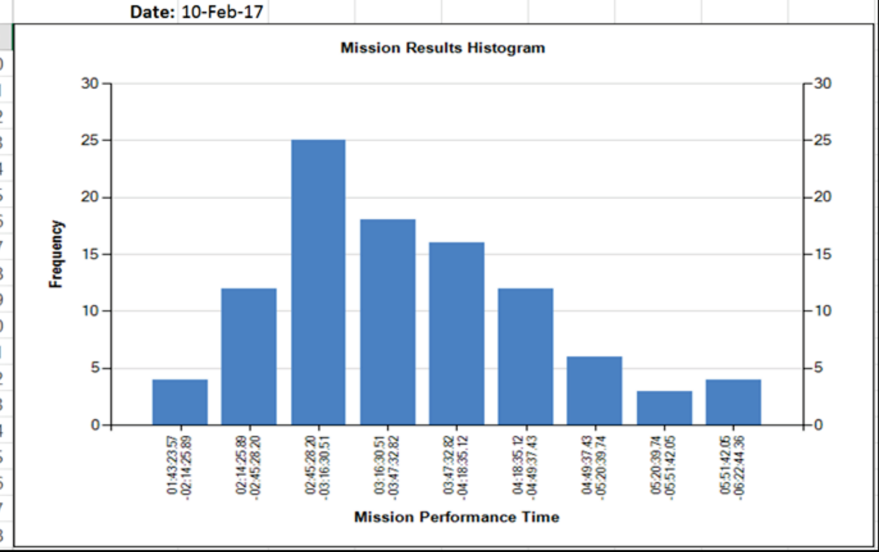

Figure D.42 Output from 100 runs of *stoplogProcedure* with the recovery *Task* showing affected times under *Cold* and *WaterDepthXSpeed Cold* and *WaterDepthXSpeed* specified as 15–32°F temperatures and 21–30 kt winds; 1 ft deep and 3 ft/s flow.

D.5 <u>Discussion</u>

D.5.1 Implementing FPM Procedures in IMPRINT Pro

Task 3 of the example MA (see Section D.3) was successfully implemented using the *Task Network* functionality of IMPRINT Pro. There are some differences in terminology used by the research team in their proof-of-concept approach and terminology used in IMPRINT Pro—in IMPRINT Pro the fundamental level is the *Task*, which is used in our approach as being equivalent to an SA. Task 3 was implemented as a *Mission* in IMPRINT Pro, one of several possible, within the *Operations Models*. Using our task analysis terminology, there are a few ways an NPP FPM procedure can be implemented within IMPRINT Pro:

1. The whole FPM procedure could be implemented as an *Analysis* (at the same level as the *stoplogProcedure*), and various MAs that compose the FPM procedure could be implemented as *Missions* within *Operations Models*. Tasks, subtasks, and SAs that compose a MA can be implemented as Tasks and grouped as necessary within the *Missions*.
2. MAs that compose an FPM procedure could be implemented as individual *Analyses*, avoiding the unnecessary complexity of implementing all MAs within one *Analysis*. *Tasks*, subtasks, and SAs that compose the MA can be implemented as *Tasks* and grouped as necessary within the single *Mission*.
3. Complicated tasks or subtasks of FPM procedures can also be implemented as *Analyses*. SAs can then be implemented as Tasks, just as in the stoplogProcedure.

The choice of whether to implement FPM procedures using IMPRINT Pro *Task Network* should be determined based on the complexity of the procedure, the number of MAs within the procedure, and the logical or logistical organization of the procedure. It is also plausible that only a few MAs within the FPM procedure are complex (i.e., consist of tasks or subtasks that may occur in parallel, require multiple crews or complex coordination, and or contain tasks that if they fail have long recovery times). These MAs could merit their own *Analysis*. A balance should be sought between the number of *Analyses* and the complexity of each *Analysis*. Breaking down an FPM procedure into too many *Analyses* may not be desirable; on the other hand, a few very complex *Analyses* may be slow to run or hard to debug. IMPRINT Pro does allow use of *Missions* already created in other *Analyses*, which can reduce effort both in terms of developing complex *Analyses* as well as needing to debug tasks and subtasks. In the framework described in the main report, SAs can be grouped into multiple, similar specific actions into categories, termed generalized actions (GAs) that are independent of site and task contexts. This approach provides a way to transfer knowledge and experience gained from relatively few site-specific task analyses across NPP sites. GAs could be analyzed in IMPRINT Pro assessed as conceptual building blocks that can be assembled to build subtasks, tasks, MAs, and FPM procedures. Therefore, it may be useful to develop *Missions* for GAs, debug them to work correctly, and reuse them in various *Analyses*.

D.5.2 IMPRINT Pro Performance Impact Assessment of Relevance to the Framework

IMPRINT Pro versions 4.1 and later have *Moderators* implemented for several ECs (i.e., *Stressors* in IMPRINT Pro terminology) of interest (*Cold, Heat, Noise*, and *Vibration*[1]), those for Level A and *MOPP* gear, the capability to use user-specified *Custom Moderators*, and user-

[1] Whole-body vibration.

developed *PSFs* as specifically compiled DLLs (Plug-Ins). IMPRINT Pro also has *Time Moderators* that can be specified to apply varying levels of a baseline PSF at the Task level or at the Operator level. For *Time Moderators*, start and end times and the corresponding *PSF* levels need to be specified.

IMPRINT Pro has nine *Taxons* in four categories:

1. Category 1: Perceptual
   a. *Taxon 1: Visual Recognition and Discrimination*
2. Category 2: Cognitive
   a. *Taxon 2: Numerical Analysis*
   b. *Taxon 3: Information Processing and Problem Solving*
3. Category 3: Motor
   a. *Taxon 4: Fine Motor – Discrete*
   b. *Taxon 5: Fine Motor – Continuous*
   c. *Taxon 6: Gross Motor – Light*
   d. *Taxon 7: Gross Motor – Heavy*
4. Category 4: Communication
   a. *Taxon 8: Oral*
   b. *Taxon 9: Reading and Writing*

IMPRINT Pro allows for up to three *Taxons* to be assigned to each *Task* (v. 4.1)—the *Taxon* weights or fractions determine the relative contribution of a *Taxon* to *Task* performance, and the three Taxon weights should add to 1.0. IMPRINT Pro also allows specification of user-defined *Taxons* in *Plug-Ins*. The proof-of-concept method described in Chapter 9 is not limited to using three PDs only. While it may be debatable whether estimating impacts on more than three PDs adds to the accuracy of overall task performance impact estimates, *Plug-Ins* can be used to implement this approach.

The extension capability of IMPRINT Pro is useful for analysts to implement the ECs that are not currently in IMPRINT Pro: lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning. *Custom Moderators* and *Plug-Ins* can be used for this purpose. The example *Task Analysis* described earlier demonstrated the use of a *Custom Moderator.* Although relatively quick to implement, Custom *Stressors* can only use *Taxons* already present in IMPRINT Pro. *Plug-Ins*, on the other hand, can be much more flexible and can implement additional *Taxons* while retaining access to all *Task, Operator*, and *Mission* data.

The ECs are expected to change with time during the performance of FPM procedures (see Section 8.3). Although *Time Moderators* could be used to vary the levels of ECs during a simulation, their implementation is somewhat limiting. *Time Moderators* can only draw from baseline *Moderators*, those already built into IMPRINT Pro. Also, start and end times and corresponding EC levels must be specified at the start of a simulation; between the start and end times, the *Time Moderator* varies the severity linearly. Therefore, time variations in ECs not currently implemented in IMPRINT Pro cannot be specified using *Time Moderators*. It may also be desirable to use varying EC levels based on probabilities of exceedances of those ECs occurring during floods of interest due to different FCMs. The Plug-In option may allow much greater control over such issues without the need to implement these functionalities in IMPRINT Pro itself.

D.6 Appendix References

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10. SUPPLEMENTARY NOTES

M. Carr

11. ABSTRACT (200 words or less)

The U.S. Nuclear Regulatory Commission is carrying out a Probabilistic Flood Hazard Assessment Research Program to risk-inform external flood hazard assessment. One initiative is to better understand the actions that nuclear power plant licensees have planned to take outside of the main control room to prepare for, protect against, and mitigate the effects of external flooding events. The Pacific Northwest National Laboratory conducted a comprehensive review of research literature describing how the environmental conditions (ECs) associated with flooding events might affect performance of flood protection and mitigation actions. This report identifies and characterizes ECs associated with flooding events: heat, cold, noise, vibration, lighting, humidity, wind, precipitation, standing and moving water, ice and snowpack, and lightning. The report identifies and characterizes a set of manual actions (MAs) that would be performed at and around NPP sites in preparation for or in response to a flooding event.

The report presents a conceptual framework that illustrates the relationships among ECs, MAs, and performance. The review of the research literature summarizes the state of knowledge concerning the effects of the ECs on human performance. The impact assessment approach is illustrated using a proof-of-concept method for an example MA.

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