HUMAN FACTORS ANALYSIS OF PIPELINE MONITORING AND CONTROL OPERATIONS:

FINAL TECHNICAL REPORT

Prepared by:

Marvin McCallum and Christian Richard

Battelle
The Business of Innovation

Prepared for:

Pipeline and Hazardous Materials Safety Administration

and

Pipeline Research Council International

November 26, 2008

This research was co-funded by the Department of Transportation, Pipeline and Hazardous Materials Safety Administration (PHMSA) and by the Pipeline Research Council International, Inc. (PRCI). The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of PHMSA or the U.S. Government.

ACKNOWLEDGEMENTS

The Battelle researchers would like to acknowledge the Government agencies, industry associations, and the individuals who supported this project.

This project was co-funded and ably co-managed by the Pipeline and Hazardous Materials Safety Administration (PHMSA) and Pipeline Research Council International (PRCI).

Several past and present managers from seven separate pipeline operating companies actively supported this project through their participation in planning meetings, coordination of company resources, and their review and comment on numerous interim project products. Risk analysis professionals from two participating companies played a critical role in shaping the final risk assessment methodology.

More than 200 individual pipeline Controllers and control room supervisors from participating companies provided the detailed operational information that allowed the resulting methodology to be tailored to the realities of pipeline monitoring and control operations through their interview participation, Controller Survey completion, and risk likelihood rating participation.

Finally, the authors of this report relied heavily on the excellent database management and analysis support provided by Jim Brown of Battelle and the outstanding administrative support, data entry, and document preparation and management skills of Diane Williams of Battelle.

EXECUTIVE SUMMARY

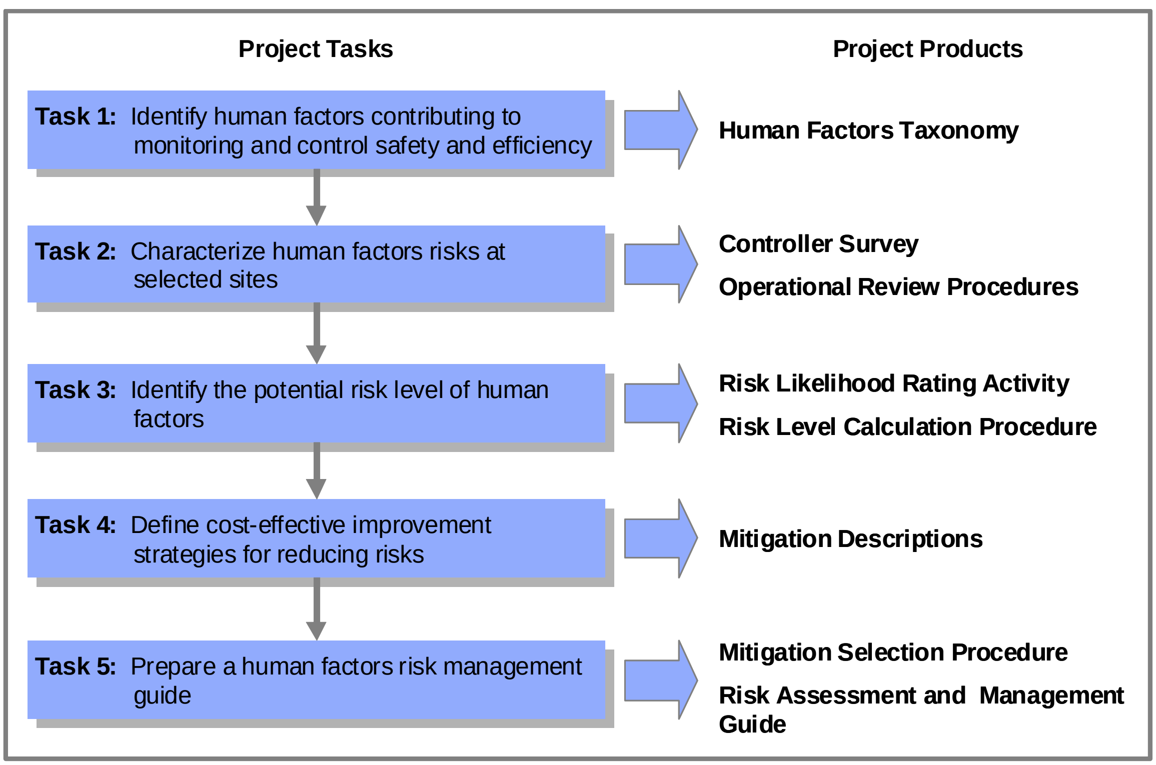
PROJECT PURPOSE AND OBJECTIVES

The purpose of the Human Factors Analysis of Pipeline Monitoring and Control Operations project was to develop procedures that could be used by liquid pipeline operators to assess and manage the human factors risks in their control rooms that may adversely affect pipeline monitoring and control operations. The three primary objectives of the project were:

1. To understand the human factors that affect pipeline Controllers' abilities to safely and efficiently monitor and control pipeline operations in the control room;
2. To develop procedures for use by pipeline operators to assess the relative risk levels associated with a full range of human factors in their control room operations; and
3. To develop a guide that liquid pipeline operators can use to select, develop, and implement mitigations to reduce operational risks associated with control room human factors.

PROJECT ACTIVITIES

This project was conducted as a series of five technical tasks. The figure below presents an overview of these tasks and the primary products resulting from each task. The following discussion described the primary activities and results corresponding to each of these tasks.



Major Project Tasks and Products

Task 1: Identify human factors contributing to monitoring and control safety and efficiency. This task consisted of three information gathering activities – a human factors literature review, an analysis of published severe accident investigation reports, and a series of structured interviews with control room personnel – to identify the human factors that contribute to pipeline monitoring and control safety and efficiency. Task 1 provided the technical basis for the development of a Human Factors Taxonomy, which is a hierarchically organized list of human factors that affect liquid pipeline monitoring and control performance. This taxonomy is comprised of 11 Human Factors Areas, 29 Human Factors Topics, and 138 Performance Factors.

Task 2: Characterize human factors risks at selected sites. This task involved the development of procedures to characterize the human factors risks in control rooms and their trial application by members of the seven operating companies participating on the project industry team. A Controller Survey was developed, which can be used to obtain Controllers' estimates regarding the prevalence of the 138 Performance Factors in their control room, along with descriptions of working conditions associated with Performance Factors that may be adversely affecting job performance. A draft version of control room operational review procedures was also developed and applied by participating operators. The operational reviews are conducted to aid in understanding the nature of specific operational risks and to identify potential strategies towards mitigating those risks.

Task 3: Identify the potential risk level of human factors. This task was conducted to develop a risk-based procedure for prioritizing potential human factors risks for subsequent mitigation and risk management activities. This task resulted in the development and trial application of a Risk Likelihood rating activity and Risk Level calculation procedure. This rating activity is used to obtain ratings of the likelihood that exposure to the working conditions associated with each Performance Factor will result in degraded Controller performance and contribute to the occurrence and/or increase in severity of an incident with an unacceptable consequence. The Risk Level calculation procedure integrates Controller Survey and Risk Likelihood rating data to prioritize Human Factors Topics and Performance Factors on the basis of their estimated Risk Level.

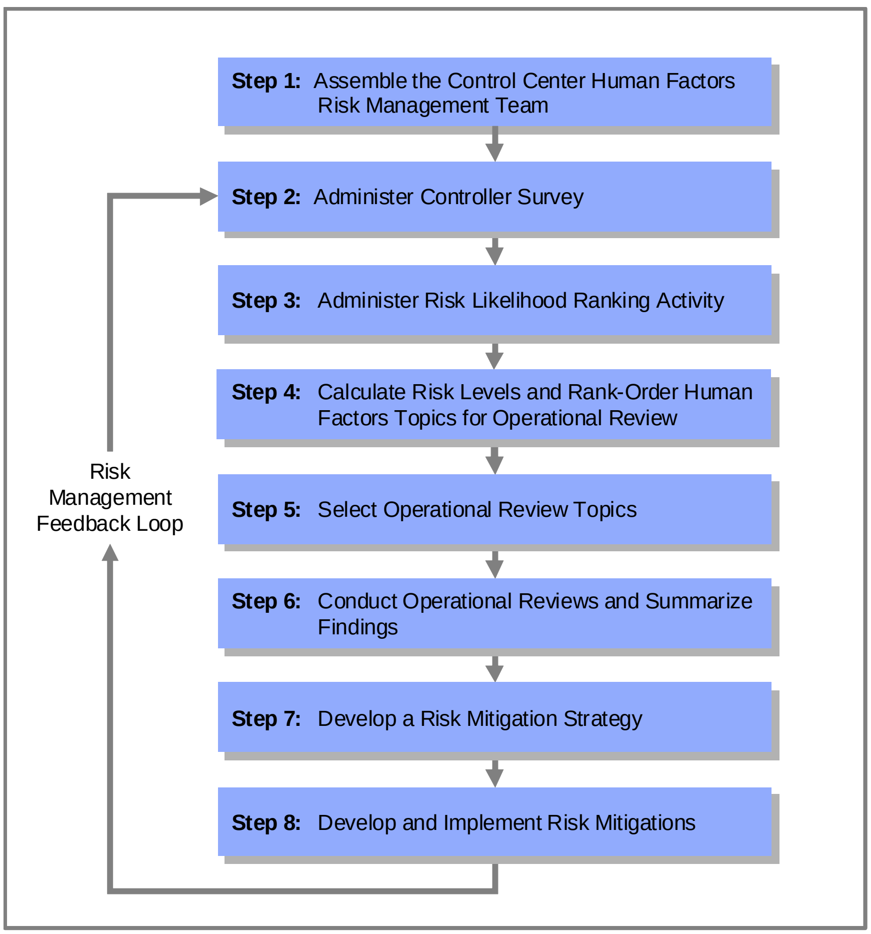
Task 4: Define cost-effective improvement strategies for reducing risks. This task was conducted to identify potential mitigations that could be developed and implemented by operators in order to reduce and manage human factors risks in their control rooms. Available theoretical, research, and applied operational literature was reviewed and integrated with operator input into a set of mitigation descriptions that can serve as an initial reference for operators in their development of a human factors risk mitigation strategy.

Task 5: Prepare a human factors risk management guide. This task involved the development of procedures and guidance for operators to use in selecting from among the potential mitigations and developing a risk mitigation strategy that best addresses their organization's potential human factors risks. The resulting procedures were incorporated along with the products of the preceding tasks into the *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide*, which is the companion document to this technical report and is referred to as the *Guide* in this report.

HUMAN FACTORS RISK ASSESSMENT AND MANAGEMENT PROCESS

The figure below provides an overview of the steps that comprise the human factors risk assessment and management process that was developed during this project and incorporated into the *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide*, which is the companion document to this technical report. The overall process consists of eight steps that are conducted by an operator to establish a human factors risk management team, identify and assess the human factors risks in their control room, develop a plan for mitigating the highest-priority risks, and then develop and implement the selected mitigations. The *Guide* provides detailed guidance, instructions, tools, and worksheets to support operators in their performance of each of these eight steps.

The process includes a risk management feedback loop, depicted on the left-hand side of the figure. Human factors risk mitigations are implemented in an effort to reduce the risk levels associated with targeted human factors. The effectiveness of implemented mitigations can be evaluated through this feedback loop by periodically assessing control room human factors risk levels associated with the targeted human factors. Conducting a periodic human factors risk assessment will both provide evidence regarding the effectiveness of implemented mitigations and help in determining appropriate future steps to further reduce potential human factors risks.



Human Factors Risk Assessment and Management Steps

LIMITATIONS OF PROJECT PRODUCTS

The current project represents a first effort in several respects. Not only was this the first comprehensive review of human factors in pipeline monitoring and control operations; but it was also the first attempt to develop a comprehensive methodology that could be applied by pipeline operators to assess and manage human factors risks in their operations. The current effort included a substantial level of trial application of procedures, as well as industry review and refinement; but that refinement could only be carried so far. Therefore, it is important to recognized several limitations in the applicability of the first-generation *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide*.

Applicability of the Guide to Other Pipeline Segments

The most fundamental limitation of the *Guide* concerns the overall structure and detailed content of the Human Factors Taxonomy. This taxonomy serves as the technical reference for several individual risk assessment and mitigation procedures. If the taxonomy is not applicable to a segment of pipeline operators, then the specific procedures that are based on the taxonomy will have limited applicability. There is good reason to be confident in the general applicability of the taxonomy's organization to the full range of pipeline operations. This general organization is based upon a broad survey of human factors issues and reflects factors that are commonly addressed in process control human factors risk management programs. In addition, the pipeline-specific content of the taxonomy is based on the analysis of severe pipeline accident reports, first-hand interviews with pipeline Controllers, and an extensive review among pipeline operational experts.

However, it is possible that detailed components of the taxonomy, as well as specific risk mitigations, will require refinements to better reflect the operational demands of other industry segments. The industry team that supported this project represented larger operators who primarily transport liquid products. So, caution should be taken when considering application of the current methodology to small- or medium-scale liquid pipeline operators; or gas pipeline operations.

Limitations of a Paper-based Guide

The current version of the *Guide* is a paper-based document that is over 400 pages in length. It contains two rating instruments, several calculation procedures, numerous worksheets and summary forms, and two major sets of guidance that are intended to support worksheet preparation. Each of the separate guide elements is intended to support a progressive, integrated process of information gathering, analysis, and documentation. Much of the information, data, and results obtained from individual steps are intended to be transferred to data sets or forms used in subsequent steps. With a paper-based set of procedures, this data transfer will either be accomplished manually; or individual operators will develop their own computer-based tools to support selected steps.

SUGGESTED FUTURE HUMAN FACTORS RISK MANAGEMENT EFFORTS

The methodology and Guide developed during this project represent significant steps towards the implementation of a comprehensive human factors risk assessment and management process in the pipeline industry. Several future activities could build upon the current products to better meet the human factors risk assessment and management needs of the pipeline industry.

Adapt the Guide to Other Liquid Pipeline Operations. The current Guide represents a substantial shift in risk management practices for many liquid operators. In addition, the applicability of the Guide to small- and medium-scale operations is not well known at this time. A coordinated, yet limited implementation effort with a sample of small-, medium-, and large-scale operators could address these limitations and establish a mechanism to make any necessary refinements to the Guide to better accommodate operational differences between the small-, medium-, and large-scale liquid operators.

Implement Procedures in Computer-Based Tools. The coordinated development of computer-based tools to support the application of the current Guide would represent a substantial savings to industry, both in total development costs and required implementation resources. It would also help to standardize the actual process that is implemented by individual operators. Near-term efforts could develop stand-alone spreadsheets and electronic forms to help operators conduct and document individual steps in the process. Two potential levels of additional computer-based tool development include: the integration of spreadsheets and forms under a single software program to facilitate data transfer and reduce resource requirements; and the linking of rating instruments, instructions, and guidance into a fully integrated computer-based Guide.

Adapt the Guide to Gas Operations. A recommended intermediate-term step is the adaptation of the Guide to gas operations. Such an activity could leverage the findings and lessons learned from the present project to produce a final Guide ready for implementation within the gas community in a relatively short period of time.

Develop Standardized Incident Investigation and Reporting Procedures. The development of standardized pipeline industry human factors incident investigation and reporting procedures could provide a valuable source of information regarding high-priority human factors issues at individual control rooms, both within industry segments and across the entire industry. The current Human Factors Taxonomy provides an excellent technical basis for developing liquid pipeline operator incident investigation and reporting procedures. Variations in the taxonomy for liquid and gas operators would likely require some variations in the detailed elements and procedures corresponding to these two industry segments.

Develop Industry Databases. Several industry-wide databases that could aid in the assessment and management of human factors risks in pipeline operations are identified as potential long-term efforts, including the following.

- A human factors incident investigation and reporting program based upon standardized incident investigation and reporting procedures would complement other ongoing human factors risk assessment and management activities.
- An industry-wide risk assessment database could be developed through the sharing of data using the first-generation computer-based tools. Such a database could provide a stable source of industry-wide risk assessment results and also provide a stable and reliable basis for reviewing common human factors concerns across the industry.
- A mitigation evaluation database could be populated by numerous industry sources to provide an empirical basis for evaluating the relative value of alternative mitigations in addressing human factors issues, both in the pipeline industry and broader process control industry.

GLOSSARY

Following are definitions for a number of terms that are used in this document to refer to specific aspects of human factors and pipeline operations.

Human Factors is the study of how the various aspects of personal characteristics and experience, job and task design, workspace design, tools and equipment design, and work environment affect both system operator and overall system performance.

Human Factors Taxonomy is the hierarchically organized list of human factors incorporated in the current Guide that is comprised of 11 Human Factors Areas, 29 Human Factors Topics, and 138 Performance Factors.

Human Factors Area is the highest level of organization in the Human Factors Taxonomy. There are 11 Human Factors Areas: 1) Task Complexity and Workload, 2) Displays and Controls, 3) Communications, 4) System Information Accuracy and Access, 5) Job Procedures, 6) Alarm Presentation and Management, 7) Controller Training, 8) Coping with Stress, 9) Controller Alertness, 10) Automation, and 11) Control Room Design and Staffing.

Human Factors Topic is the intermediate level of organization in the Human Factors Taxonomy. Each of 29 Human Factors Topics is nested within one of the 11 Human Factors Areas, and is comprised of a group of related Performance Factors.

Performance Factor is the most detailed level of organization in the Human Factors Taxonomy. Each of 138 Performance Factors represents specific human factors control room working conditions, including the characteristics of Controllers (e.g., experience, fatigue), workspaces (e.g., display monitors, lighting), job tools (e.g., batch tracking, SCADA), job design (e.g., control tasks and activities), and other factors that affect the Controller's ability to effectively monitor and control pipeline operations.

Controller Survey is a survey administered to Controllers that obtains both their ratings regarding the Prevalence with which they encounter each of 138 Performance Factors included in the Human Factors Taxonomy and their descriptions of working conditions associated with Performance Factors that may be adversely affecting their job performance.

Working Conditions are the specific operating conditions or factors that Controllers encounter at their work site while conducting pipeline monitoring and control activities and other related tasks. Working Conditions are associated with specific Performance Factors (e.g., workload problems at a specific console, specific field technician communications problems, specific alarms that are a particular nuisance, etc.).

Prevalence is the estimated level of Controllers' exposure to working conditions associated with a Performance Factor in their control room. Prevalence is seen as influencing operational risk and efficiency by increasing Controllers' exposure to conditions that may adversely affect their monitoring and control performance.

Risk Likelihood is the rated likelihood that exposure to the working conditions associated with a Performance Factor will directly lead to sub-optimal Controller pipeline monitoring and control performance and thereby cause or contribute to the occurrence and/or increase in severity of an incident with an unacceptable consequence.

Risk Level is the relative risk at a control room that working conditions associated with a Performance Factor or Human Factors Topic will be present, that those working conditions will adversely affect Controller pipeline monitoring and control performance, and that the degraded performance will result in the occurrence and/or increase in severity of an incident with an unacceptable consequence.

Control Room Operational Reviews are activities conducted to supplement information obtained from the Controller Survey and Risk Likelihood rating activity that help in understanding the nature of specific operational risks and potential mitigations of those risks. Types of operational review information collection activities include: 1) accident, incident, and near-incident report review; 2) Controller interview; 3) observational review; and 4) materials review.

Mitigations represent changes that can be made to working conditions, operating practices (e.g., workspace layout, training, software design, job requirements, procedures, etc.), and system design to improve overall system performance and reduce operational risk.

Supervisory Control and Data Acquisition (SCADA) systems are computer based tools that provide an integrated summary of remote pipeline sensors and controls. Pipeline Controllers engaged in SCADA operations to monitor and control pipeline operations from a console in a pipeline control room, which is typically equipped with multiple SCADA consoles used to monitor and control separate sections of a larger pipeline system.

TABLE OF CONTENTS

LIST OF FIGURES, TABLES AND EQUATIONS

PROJECT BACKGROUND AND INTRODUCTION

BACKGROUND

The job of monitoring and controlling pipeline operations from a remote control room is similar to system operation jobs in several other complex process control industries, such as nuclear power, petroleum refinery, and air transportation. Each of these jobs requires operators to maintain awareness of the status of a complex system as they control an ongoing process so that it remains within prescribed limits of safety and efficiency. In most cases, these monitoring and control operations are performed with the aid of remote sensors, automated display and control systems, and communications with other individuals who monitor and control interacting elements of the larger, integrated system.

Research in process control safety and efficiency has resulted in an increasing awareness of the many 'human factors' in the operational environment that directly affect the monitoring and control performance of the system operator. Since operator performance is often critical in maintaining a process within limits and responding to abnormal conditions, these human factors can have a substantial affect on the ultimate safety and operational effectiveness of an entire system. As a result, systematic and long-term efforts have been undertaken in several high-risk process control industries to mitigate the risks associated with human factors by modifying the operator's job, tasks, and work environment to better support operator performance; as well as to introduce additional system defenses to reduce the consequences of human error.

Some of the most noteworthy efforts to understand and address the role of human factors have been in the nuclear power and aviation industries. In these industries, broadly-based efforts have been undertaken to understand the risks associated with human factors and provide guidance to industry operators in how to best mitigate these risks. Investigations of severe pipeline accidents conducted by the National Transportation Safety Board (NTSB) have identified human factors as contributors to some of those accidents. However, prior to the present project, a comprehensive investigation of the human factors that affect pipeline monitoring and control operations had not been conducted. Consequently, pipeline operators have had limited empirical evidence to guide their efforts to reduce operational risks resulting from human factors that adversely affect pipeline Controller monitoring and control performance.

PROJECT PURPOSE AND OBJECTIVES

The purpose of the current project was to develop procedures that could be used by liquid pipeline operators to assess and manage the human factors risks in their control rooms that may adversely affect pipeline monitoring and control operations. The three primary objectives of the project were:

1. To understand the human factors that affect pipeline Controllers' abilities to safely and efficiently monitor and control pipeline operations in the control room;
2. To develop procedures for use by pipeline operators to assess the relative risk levels associated with a full range of human factors in their control room operations; and
3. To develop a guide that liquid pipeline operators can use to select, develop, and implement cost-effective mitigations to reduce operational risks associated with control room human factors.

PROJECT TEAM

This project was led by a team of researchers from Battelle, a non-profit research institute, and a team of pipeline operations managers, representing seven liquid pipeline operators, under the sponsorship of the Pipeline Research Council International (PRCI). Each task of the project involved a joint effort by Battelle and industry team members to accurately define the human factors affecting pipeline monitoring and control operations, to develop procedures that could be applied by operators in assessing and managing those risks, and to translate those procedures into a usable and comprehensible guide.

PROJECT ACTIVITIES

This project was conducted as a series of five technical tasks. Figure 1 presents an overview of these tasks and the primary products resulting from each task, which are described briefly below.

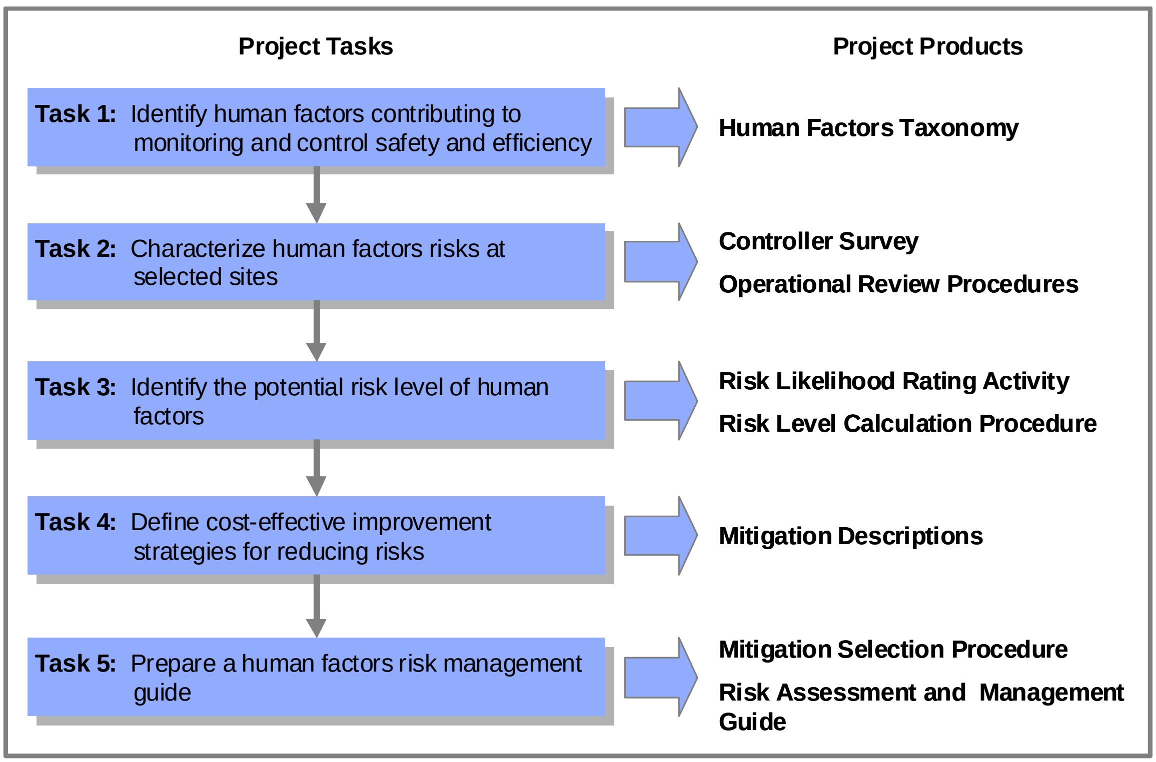


Figure 1. Major Project Tasks and Products

Task 1 consisted of three information gathering activities – a human factors literature review, an analysis of published severe accident investigation reports, and a series of structured interviews with control room personnel – to identify the human factors that contribute to pipeline monitoring and control safety and efficiency. Task 1 provided the technical basis for the development of a Human Factors Taxonomy, which is a hierarchically organized list of human factors that affect liquid pipeline monitoring and control performance. This taxonomy is comprised of 11 Human Factors Areas, 29 Human Factors Topics, and 138 Performance Factors.

Task 2 involved the development of procedures to characterize the human factors risks in control rooms and their trial application by members of the project's industry team. Two basic tools were developed and applied on a trial basis during this task. First, a draft version of a Controller Survey was developed, which can be used to obtain Controllers' estimates regarding the prevalence of the 138 Performance Factors in their control room, along with descriptions of working conditions associated with Performance Factors that may be adversely affecting job performance. Second, a draft version of control room operational review procedures was developed and applied by participating operators. These procedures define activities that can be conducted to supplement initial risk assessments to aid in understanding the nature of specific operational risks and to identify potential strategies towards mitigating those risks.

Task 3 was conducted to develop a risk-based procedure for prioritizing potential human factors risks for subsequent mitigation and management activities. This task resulted in the development and trial application of a Risk Likelihood rating activity and Risk Level calculation procedure. This rating activity is used to obtain ratings of the likelihood that exposure to the working conditions associated with each Performance Factor will result in degraded Controller performance and contribute to the occurrence and/or increase in severity of an incident with an unacceptable consequence. The Risk Level calculation procedure integrates Controller Survey Prevalence rating data and Risk Likelihood rating data to prioritize Human Factors Topics and Performance Factors on the basis of their estimated Risk Level.

Task 4 was conducted to identify potential mitigations that could be developed and implemented by operators in order to reduce and manage human factors risks in their control rooms. Available theoretical, research, and applied operational literature was reviewed and integrated with operator input into a series of mitigation descriptions that can serve as an initial reference for operators in their development of a human factors risk mitigation strategy.

Task 5 involved the development of procedures and guidance for operators to use in selecting from among the potential mitigations and developing a risk mitigation strategy that best addresses their organization's potential human factors risks. The resulting procedures were incorporated along with the products of the preceding tasks into the *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide*, which is the companion document to this technical report and is referred to as the *Guide* in this report.

RISK MANAGEMENT METHODOLOGY OVERVIEW

Much of the theoretical foundation for the methodological approach adopted in the present project stems from publications by James Reason, beginning in the 1990's (cf. Reason, 1990; Reason, 1995). Reason's seminal publication, *Human Error*, integrated earlier theoretical and applied research addressing the role of human performance in industrial accidents. Two conceptualizations in Reason's work that were particularly influential to the present effort addressed: (1) the causal roles of different factors in critical incidents; and (2) the role of multiple defenses in minimizing the risks associated with human performance. Figure 2 depicts the opposing sequences of critical incident investigation activities and causes reflected in Reason's work. Starting from the investigation perspective, one or more unsafe acts (such as the misdiagnosis of an abnormal condition or an incorrect control action) are typically identified as the proximal cause of an incident in which human performance was a contributing factor. Following this model, an incident investigation may or may not continue to consider workplace factors (such as displays and control layouts) or operational factors (such as job design and abnormal situation training) that may have also contributed to the occurrence of the unsafe acts.

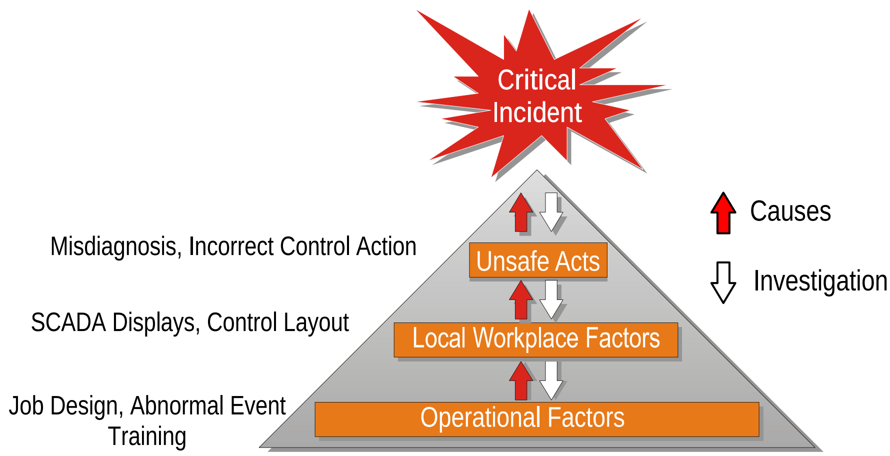


Figure 2. Sequence of Human Factors-Related Incident Investigation Causes

The current methodology adopts Reason's fundamental assertion that the causes of unsafe acts represent the full range of human performance, local workplace, and operational factors. For example, if an inappropriate control response to an abnormal incident were identified as the unsafe act preceding a product leak, one contribution to that incident could be identified as the Controller misdiagnosing the nature of the abnormal condition. However, further analysis could reveal that a factor contributing to the Controller's misdiagnosis was the layout of the physical pipeline on the Supervisory Control and Data Acquisition (SCADA) display that made it difficult to determine the status of the affected portion of the pipeline system. Further analysis of the Controller's misdiagnosis could reveal that an additional factor contributing to this unsafe act was the limited ability of the Controller to mentally focus on the abnormal conditions; due to a job design that required concurrent monitoring and control of several ongoing pipeline activities. Thus, a very fundamental premise of the present effort is that the full range of operator, local workplace, and operational factors can contribute to the occurrence of an incident.

A second conceptualization of Reason's that is reflected throughout the current project deals with the role of multiple defenses in minimizing the risks associated with human performance. Figure 3 graphically illustrates this second conceptualization in what is often referred to as Reason's 'Swiss Cheese' model of accident causation. This figure depicts the trajectory of critical incident opportunities and the value of multiple, redundant system defenses or incident barriers. Figure 3 depicts the basic assertion that the trajectory of most potential incidents resulting from a hazardous situation can be avoided through the design and implementation of multiple effective system defenses. Effective redundant defenses (such as redundant sensors that provide overlapping information regarding system status, automated alarm management that facilitates access to critical information, and relief valves that minimize the result of over-pressurization) reduce the likelihood that a hazardous situation will result in an actual incident. In summary, the current project has adopted the fundamental assertion that a combination of mitigations that are developed to augment Controllers' capabilities, better match job requirements to Controllers' capabilities, and introduce additional system defenses can provide a comprehensive means of effectively reducing human factors risks in a control room.

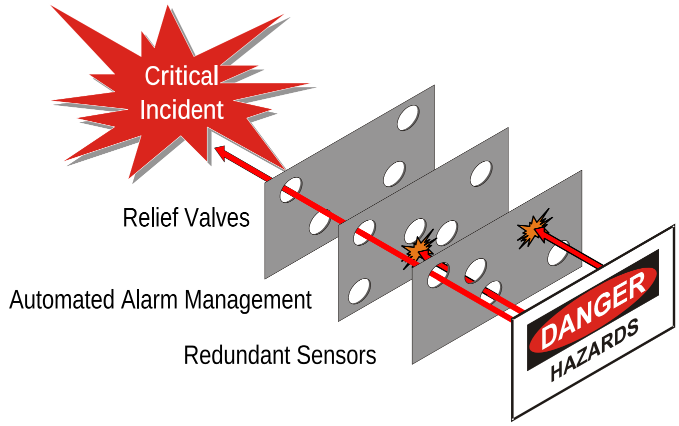


Figure 3. Incident Causes and Defenses (Adapted from Reason, 1990)

Figure 4 provides an overview of the human factors risk assessment and management methodology activities developed during this project. The overall methodology consists of eight steps that are conducted by an operator to establish a human factors risk management team, identify and assess the human factors risks in their control room, develop a plan for mitigating the highest-priority risks, and then develop and implement the selected mitigations. The *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide* provides detailed guidance, instructions, tools, and worksheets to support operators in their performance of each of these eight steps.

The methodology includes a risk management feedback loop, depicted on the left-hand side of Figure 4. Human factors risk mitigations are implemented in an effort to reduce the risk levels associated with targeted human factors. The effectiveness of implemented mitigations can be evaluated through this feedback loop by periodically assessing control room human factors risk levels associated with the targeted human factors. Conducting a periodic human factors risk assessment will both provide evidence regarding the effectiveness of implemented mitigations and help in determining appropriate future steps to further reduce potential human factors risks.

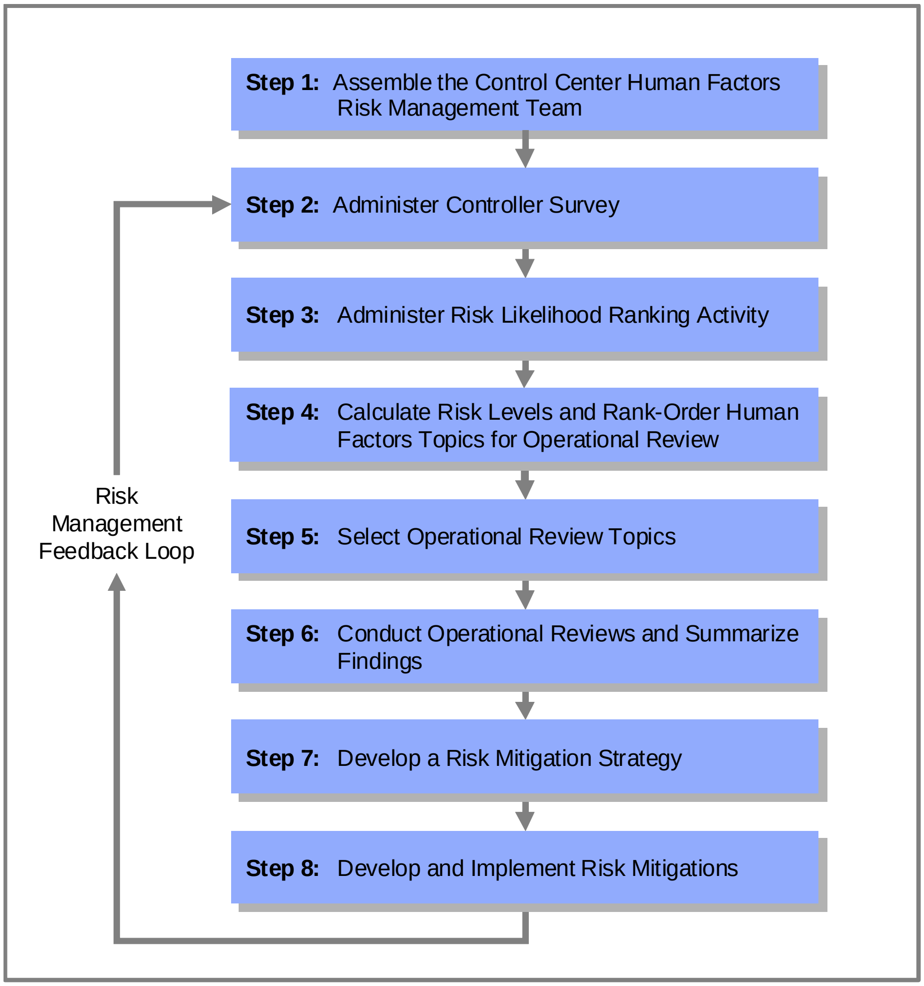


Figure 4. Overall Control Room Risk Management Methodology Activities

TECHNICAL REPORT ORGANIZATION

The remainder of the main body of this technical report is divided into five sections. The next four sections describe the project activities, findings, and products corresponding to four major topics: Control Room Human Factors Identification, Human Factors Risk Assessment, Control Room Operational Reviews, and Risk Mitigation Selection and Development. A final section of the main body presents the research team's Conclusions and Recommendations. In addition, a series of seven appendices provide further detail regarding the methods and findings associated with individual research activities.

CONTROL ROOM HUMAN FACTORS IDENTIFICATION

The current project took advantage of past theoretical and empirical research to gain an initial understanding of the human factors that may be affecting pipeline monitoring and control operations. Then, an analysis of severe accident investigation reports published by the NTSB was conducted to better understand potential human factors risks in pipeline control room operations. These sources of information were then augmented by a series of structured interviews conducted by Battelle project researchers with control room staff to better understand the specific operational challenges they face. Finally, these three sources of information were integrated into an initial taxonomy that provided a hierarchical classification of a broad range of human factors that might potentially affect pipeline monitoring and control performance in a control room. The initial Human Factors Taxonomy was then refined on the basis of operator team members' review. The methods and findings associated with each of these activities are discussed in the remainder of this section.

HUMAN FACTORS LITERATURE REVIEW

Since the Three Mile Island nuclear power plant accident in 1979, there has been a substantial level of theoretical and empirical research addressing the factors that influence the performance of operators who monitor and control complex, safety-sensitive industrial process control systems. This research has led to a broader understanding and appreciation of the factors that affect monitoring and control performance, and the strategies that can be employed to mitigate operational risks associated with such factors. The current project took advantage of this past research to provide an initial understanding of these two topics.

Literature Search Strategy and Results

Computerized searches of public domain literature were conducted at two separate times. An initial search was conducted in December 2003 as part of an earlier, industry-funded project that was intended to complement the current project. Human factors, process control engineering, safety, and social sciences publication databases were searched, including the following databases and publication periods: NTIS (1964-2003), TRIS (1970-2003), INSPEC (1969-2003), Ei Compendex (1970-2003), PsycINFO (1887-2003), and Energy SciTec (1974-2003). A relatively exhaustive set of search terms were used to identify literature that addressed the issues of: (1) safety, risk, efficiency, operations, control, improvement, cost-benefit, or human factors; within the operational domains of (2) process control, plant operations, batch processing, power generation, nuclear power, chemical industries, petroleum industry, or pipeline industry. Following the initial search, additional terms were used to refine the resulting document set. When completed, this first literature search resulted in the identification of 3,479 relevant articles. The titles, reference information, and abstracts of these articles were compiled into a Reference Manger™ database for ready access during the earlier and current project and selected documents were obtained for detailed review.

The first literature search was extended during the current project in December 2005 by searching the same document databases and using the same search terms to identify relevant articles published between December 2003 and December 2005. This second search resulted in the identification of 559 potentially relevant publication titles, 66 publication abstracts warranting closer review, and the acquisition of 16 relevant publications for review and filing in the project literature Reference Manger™ database. Subsequent to the second literature search, a number of additional publications were brought to the attention of the Battelle researchers. These publications were reviewed for relevance and obtained for detailed analysis if they were determined to be relevant to the remaining project activities.

Literature Analyses and Findings

The obtained literature was reviewed to support the two broader objectives of: (1) identifying human factors topics and taxonomies with potential relevance to pipeline monitoring and control operations; and (2) identifying mitigations for reducing operational risks associated with human factors. The general literature findings corresponding to these two topics are discussed below.

Identification of human factors topics and taxonomies. The work of James Reason and its influence on the basic methodological approach of the current project is discussed in the Background and Introduction section of this report. In addition to Reason's work, a number of additional authors concerned with the basic characterization of human performance and human error in process control contributed substantially to the basic methodological approach of this project. In particular, the work of Thomas Sheridan, much of which is referenced in his recent book, *Humans and Automation: System Design and Research Issues*, (Sheridan, 2002) provided useful insights regarding the various levels of automation and allocation of functions between automated systems and human operators. In addition, the recent works by Kim Vicente and his colleagues (Vicente, 1999; Vicente, Roth, & Mumaw, 2001) have served as a valuable reference in our efforts to analyze, interpret, and characterize pipeline monitoring and control job demands.

The basic strategy of classifying and categorizing the factors that influence human performance are fundamental to behavioral science. As noted in the Background and Introduction section, the current methodology has adopted a broad 'systems' perspective with respect to the factors affecting human performance – that is, that organizational, workplace, and personnel factors can all interact to influence human performance and operational risk. Given that assumption, the project team's researchers endeavored to conduct a broad review of human factors and accident causal factor taxonomies in an effort to ensure that the current methodology reflected a comprehensive consideration of such factors. A very fundamental conceptualization introduced by Jens Rasmussen (see Rasmussen, 1982; Rasmussen, 1983) and subsequently adopted by James Reason (Reason, 1990) is the distinction between skill-, rule-, and knowledge-based behavior and the characterization of human errors and factors contributing to errors that are associated with each of these types of behavior. Although not explicitly reflected in the current methodology, this framework served as a useful referent when considering the comprehensiveness of the taxonomy that evolved during the current effort.

More specific human factors taxonomies that served as general models and as sources for comparison to ensure that the final taxonomy developed during this project was comprehensive included accident investigation programs developed for the nuclear power industry (Paradies, Unger, Haas, & Terranova, 1993), the aviation industry (Shappell & Wiegmann, 2000), and the broader transportation industry (Transportation Safety Board of Canada, 1998). In addition, two recent efforts to provide practical guidance to industrial accident investigators (Strauch, 2002; Dekker, 2002) also provided a useful basis for reviewing the evolving taxonomy developed during the current project.

Specific human factors areas and issues were identified in several of the obtained research publications. A discussion of these findings, along with the citation of specific references, is provided in Appendix A.

Identification of mitigations for reducing operational risks associated with human factors. The project team's effort to identify specific human factors mitigations involved the review of general human factors engineering design standards, several books written to provide general guidance regarding process control risk mitigation, and individual publications that addressed specific mitigation topics. General human factors engineering design standards included those for Department of Defense acquisitions (Department of Defense, 1999), aviation system acquisitions (Ahlstrom & Longo, 2003), and nuclear power control room systems (O'Hara, Brown, Persensky, Lewis, & Bongarra, 2004; O'Hara, Higgins, Lewis, & Persensky, 2002). In addition, a recently published *American Petroleum Institute Recommended Practice for Pipeline SCADA Displays* (API, 2008) provided useful guidance specific to pipeline SCADA design criteria.

A basic reference that addresses a full range of risk reduction approaches is *Lee's Loss Prevention in the Process Industries* (Mannan [ed.], 2005). This document served as a useful reference in reviewing several individual mitigation topics, as well as a general reference regarding risk assessment methodologies. Books written to specifically address human factors in process industries that also served as general references in identifying mitigations included *Guidelines for Preventing Human Error in Process Safety* (Center for Chemical Process Safety of the American Institute of Chemical Engineers, 1994); *Ergonomic Solutions for the Process Industries,* (Attwood, Deeb, & Danz-Reece, 2004), and *Human Factors Methods for Improving Performance in the Process Industries* (Crowl [ed.], 2007).

As part of the guidance prepared for operators during this project, descriptions of 86 separate human factors risk mitigations were prepared and included in the *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide*. When specific references addressing the nature, applicability, or efficacy of individual mitigations were identified, these publications were reviewed and cited in the Guide.

NTSB SEVERE ACCIDENT REPORTS ANALYSIS

A number of severe pipeline accidents that were investigated by the NTSB in recent years were found to have human factors contributing to the occurrence or severity of those accidents. The reports of these NTSB accident investigations helped to raise awareness of the importance of considering human factors in pipeline operations risk management. The project research team wanted to explicitly ensure that the individual factors identified in these accident investigations were reflected in the human factors topics addressed by this project. Therefore, a separate analysis of these accident reports was conducted.

Ten NTSB accident investigations were selected, based on a recommendation by Rob Malloy of NTSB, who was involved in an ongoing analysis of SCADA-related pipeline accidents. Most of these accident reports were subsequently reviewed in the Board's *SCADA in Liquid Pipelines* Safety Study (National Transportation Safety Board, 2005). Table 1 provides a summary of the location, date, material released, gallons released, and the estimated damage and/or clean-up cost for each of these accidents. Each of the investigation reports for the accident summarized in Table 1 explicitly defines actions taken by Controllers or their supervisors that were judged by the investigation team to contribute to the occurrence or severity of the spill. Each of these reports also provides a useful level of detail in the reconstruction of events and Controllers' reported decisions throughout the incident.

Table 1. Summary of 10 NTSB Severe Pipeline Accident Investigation Reports Selected for Analysis

Location	Month/ Year	Material Released	Gallons Released	Damage/ Clean Up Cost
Gramercy, LA	May 1996	Gasoline	475,000	$7,000,000
Fork Shoals, SC	June 1996	Fuel Oil	957,600	$20,500,000
Tiger Pass, LA	Oct. 1996	Natural Gas	Not Applicable	Unknown
Murfreesboro, TN	Nov. 1996	Diesel fuel	84,700	$5,700,000
Sandy Springs, GA	Mar. 1998	Gasoline	30,000	$3,200,000
Knoxville, TN	Feb. 1999	Diesel fuel	53,550	$7,000,000
Bellingham, WA	June 1999	Gasoline	237,000	$45,000,000
Winchester, KY	Jan. 2000	Crude oil	489,000	$7,100,000
Greenville, TX	Mar. 2000	Gasoline	564,000	$18,000,000
Chalk Point, MD	April 2000	Fuel oil	140,400	$71,000,000

NTSB Report Analysis and Results

The ten selected accident investigation reports were first analyzed to identify unsafe acts on the part of pipeline Controllers. Each of 33 Controller actions reported as contributing to the accident under investigation was assigned to one of eight unsafe act categories. Table 2 provides a summary of the distribution of identified unsafe act category assignments across the ten accident reports. A review of this table indicates a range of frequencies, but the inclusion of all eight unsafe act categories across this sample of ten accidents. This broad distribution supports the adoption of a comparably broad consideration of human factors that may affect pipeline monitoring and control performance.

Table 2. Summary of Unsafe Act Frequency across the 10 NTSB Severe Pipeline Accident Investigation Reports

Unsafe Act Category	Frequency of Unsafe Act
Receive Information	4
Set Information System Output	5
Request Information	1
Recognize Information Relevance	3
Apply Decision Rules	3
Determine Abnormal Event Nature and Location	7
Request Information	1
Apply Appropriate Operational Procedures	9

The ten NTSB accident reports were then analyzed to identify any attribution by the NTSB investigators of human factors that had contributed to each of the 33 unsafe acts. This analysis used a preliminary taxonomy of Human Factors Areas and issues that was emerging as part of the ongoing analysis effort. This second analysis led to the identification of 48 instances of human factors contributions. Table 3 provides a summary of the frequency of these contributions across each of the 11 Human Factors Areas. Review of Table 3 reveals a broad range of frequencies, ranging from 0 to 11, with just one area, *Control Room Design and Staffing*, having a frequency of zero. This latter case likely reflects the general difficulty in assigning a causal relationship between accidents and control room design and staffing levels (see Figure 2 and the corresponding discussion). The broad distribution of Human Factors Areas found in this analysis lends further support to a comparably broad consideration of human factors that may affect pipeline monitoring and control performance.

Table 3. Frequencies of 48 Instances of Human Factors Contributing to 33 Unsafe Acts in 10 NTSB Accident Investigation Reports

Human Factors Area	Frequency as a Contributing Factor
Task Workload and Complexity	7
Displays and Controls	7
Communications	2
System Information Accuracy and Access	7
Job Procedures	5
Alarm Presentation and Management	4
Controller Training	11
Coping with Stress	1
Controller Alertness	1
Automation	1
Control Room Design and Staffing	0

CONTROLLER INTERVIEWS

An important goal of the current project was to obtain a substantial level of first-hand input from pipeline operators to support the definition of human factors that affect the operational risks associated with pipeline monitoring and control operations. The initial technique for obtaining this input was to conduct a series of confidential interviews with pipeline Controllers to obtain their first-hand descriptions of the factors that affect the safety and efficiency of the operations under their responsibility.

Controller Interview Process

Interviews were conducted with 43 Controllers from seven participating companies to obtain first-hand reports about both (1) general conditions related to human factors that affected operational safety, reliability, and efficiency, and (2) human factors that contributed to a specific incident. The Controller interviews were confidential, with only one Controller and the two Battelle research staff present at the interview. Each discussion of general operating conditions followed an established script that addressed the Human Factors Areas identified in a preliminary Human Factors Taxonomy (see Table 3). Each topic was discussed in terms of both factors that negatively affected operating safety and efficiency and factors that helped improve operating safety and efficiency.

Human factors topics were introduced to each Controller in a standard order and explained using a common definition. While each Controller was asked a consistent set of questions, the interview maintained an “open-ended” response format that allowed the interviewers to ask follow-up questions and expand on topics of interest. This approach provided the structure necessary to ensure that all topics were considered sufficiently, while at the same time providing the flexibility needed to focus on new issues that Controllers identified as affecting their job performance.

The incident interviews used a version of the *critical incident technique*, which has proven especially valuable to researchers and analysts in understanding how human factors can compromise safety, reliability, and efficiency in complex human-technology systems (Shattuck & Woods, 1994). This method elicits descriptions of off-normal operational events from staff who were either involved individuals or first-hand observers. A combination of incidents identified in advance by participating operators and incidents identified by Controllers at the time of the interviews resulted in the identification and review of 40 separate incidents that were judged to be relevant to human factors issues by the project research team.

Controller Interview Analysis and Findings

The Controllers’ responses to each interview question were summarized and submitted back to each participating Controller for their review, editing, and authorization for further use. All 43 Controllers reviewed these summaries, provided changes as appropriate, and authorized further use of the results. A content analysis of Controller responses to each interview question was then performed. For each question, individual Controller responses were combined into a single list, and then responses within the list were grouped together into common themes. In most cases, these common themes indicated the specific human factors issues associated with each topic, and the responses provided details of the various aspects of those issues and the wording that could be used to communicate them. Each theme was summarized with a specific written description, and a representative example response was selected for the content analysis summary, which is presented in Appendix B.

Table 4 presents the percentage of Controllers at each of the seven operators who indicated that each of the Human Factors Areas in the preliminary taxonomy had a negative effect on operational safety and/or efficiency. The right-hand column of Table 4 provides the average percentage of Controllers across the seven companies. Review of these average percentages reveals a range of between 17% and 72% of Controllers identifying a Human Factors Area as having some negative effect.

Table 4. Percentage of Controllers Indicating that Each Human Factors Area had a Negative Effect on Operational Safety and/or Efficiency

Human Factors Area	Company							
	A	B	C	D	E	F	G	Average
Task Workload and Complexity	57%	100%	33%	80%	67%	20%	83%	63%
Displays and Controls	75%	100%	17%	33%	100%	80%	50%	65%
Communications	100%	100%	33%	50%	100%	40%	83%	72%
System Information Accuracy and Access	63%	17%	67%	40%	50%	40%	83%	51%
Job Procedures	88%	33%	33%	0%	50%	0%	50%	36%
Alarm Presentation and Management	88%	67%	83%	33%	83%	40%	100%	71%
Controller Training	71%	50%	17%	0%	17%	40%	67%	37%
Coping with Stress	43%	67%	83%	33%	67%	40%	50%	55%
Controller Alertness	43%	60%	100%	67%	40%	60%	83%	65%
Automation	13%	17%	0%	33%	33%	0%	33%	18%
Control Room Design and Staffing	38%	33%	0%	0%	17%	0%	33%	17%
Number of Participating Controllers	**8**	**6**	**6**	**6**	**6**	**5**	**6**	**43**

The 40 incidents addressed in the Controller interviews were classified into the five categories of *Product Release, Line Block or Overpressure, Product Mixing, Delivery Delay, and Incident Mitigation.* Table 5 presents the frequencies of each type of incident that was addressed in the interviews. A review of this table reveals a relatively even distribution among the Product Release, Line Block, and Product Mixing categories, which comprised the bulk of incident types. It is important to note that these frequencies do not represent the distribution of actual types of incidents in the field, since the distribution of company-supplied reports reflected the research team's request to provide a mix of different types of incidents, and the observed frequencies confirms that this objective was met.

Table 5. Frequencies of the Incident Types among the 40 Incidents Indentified in the Controller Interviews

Incident Type	Frequency (%)
Product Release	11 (28%)
Line Block or Over Pressure	9 (23%)
Product Mixing	12 (30%)
Delivery Delay	3 (8%)
Incident Mitigation	4 (10%)
Other	1 (3%)

Each incident discussion followed an established script that addressed the same set of 12 Human Factors Areas that were addressed in the discussion of general operational conditions. In reviewing these Human Factors Areas, Controllers were asked to identify whether or not each

Human Factors Area contributed to the occurrence or severity of the incident under review. Table 6 provides a summary of the percentage of Controllers who indicated that a specific Human Factors Area did contribute to the incident under discussion. Contribution percentages ranged from 9% to 40%, indicating both a fairly substantial range; but also the involvement of each of these general Human Factors Areas in the incidents that were analyzed.

Table 6. Percentage of Controllers Indicating that a Human Factors Area Contributed to the Incident under Review

	Company							
Human Factors Area	A	B	C	D	E	F	G	Average
Task Workload and Complexity	0%	83%	20%	17%	83%	20%	50%	39%
Displays and Controls	67%	50%	0%	17%	33%	0%	33%	29%
Communications	33%	17%	60%	17%	50%	40%	33%	36%
System Information Accuracy and Access	67%	50%	40%	33%	17%	40%	33%	40%
Job Procedures	50%	33%	50%	50%	33%	0%	17%	33%
Alarm Presentation and Management	17%	33%	20%	50%	50%	20%	17%	30%
Controller Training	0%	17%	0%	33%	17%	0%	17%	12%
Coping with Stress	0%	17%	0%	33%	17%	20%	50%	20%
Controller Alertness	0%	33%	0%	0%	0%	0%	33%	9%
Automation	33%	33%	0%	0%	0%	20%	0%	12%
Control Room Design and Staffing	33%	40%	20%	0%	0%	0%	0%	13%
Number of Participating Controllers	**6**	**6**	**5**	**6**	**6**	**5**	**6**	**40**

The findings from the Controller interviews, combined with the analysis of NTSB severe accident reports, had a significant influence on the course of the current project. At its inception, the project team had planned to reduce the number of human factors considered during later stages of the project. This plan reflected the intent to develop an effective and efficient means of assessing human factors risks, while avoiding the use of resources in assessing areas associated with minimal risks. The results of the accident report and interview analyses suggested that none of these Human Factors Areas could be excluded from an initial assessment of the human factors risks at an individual control room. Therefore, the project re-focused its efforts in an attempt to develop an efficient and effective means of initially assessing the potential risks associated with a comprehensive set of human factors.

HUMAN FACTORS TAXONOMY DEVELOPMENT

The technical reference used in identifying and organizing potential human factors risks and mitigations throughout the risk assessment and management procedures defined by this methodology is the *Pipeline Operations Human Factors Taxonomy*. This taxonomy was drafted on an ongoing basis during the project research team's analysis of the three information sources described in the preceding discussions: the human factors literature review, pipeline accident investigation reports, and the Controller interviews. Following the drafting of a full taxonomy, it was submitted to the industry team for an iterative process of industry review and research team refinement. The basic objectives in conducting this revision were to ensure that a comprehensive set of human factors were represented in the taxonomy, to use language that was well-understood by members of industry, and to employ a common style of language across all elements of the taxonomy.

Figure 5 graphically depicts the basic organization of the Pipeline Operations Human Factors Taxonomy, omitting many of the details. The most general *Human Factors Area* level of the taxonomy consists of 11 areas: (1) Task Complexity and Workload, (2) Displays and Controls, (3) Communications, (4) System Information Accuracy and Access, (5) Job Procedures, (6) Alarm Presentation and Management, (7) Controller Training, (8) Coping with Stress, (9) Controller Alertness, (10) Automation, and (11) Control Room Design and Staffing.

The intermediate *Human Factors Topic* level of the taxonomy includes 29 Human Factors Topics nested within the Human Factors Areas. For example, as depicted in the figure, there are two Human Factors Topics nested within Human Factors Area 1: 1.1.—Task Design and 1.2.—Console Workload.

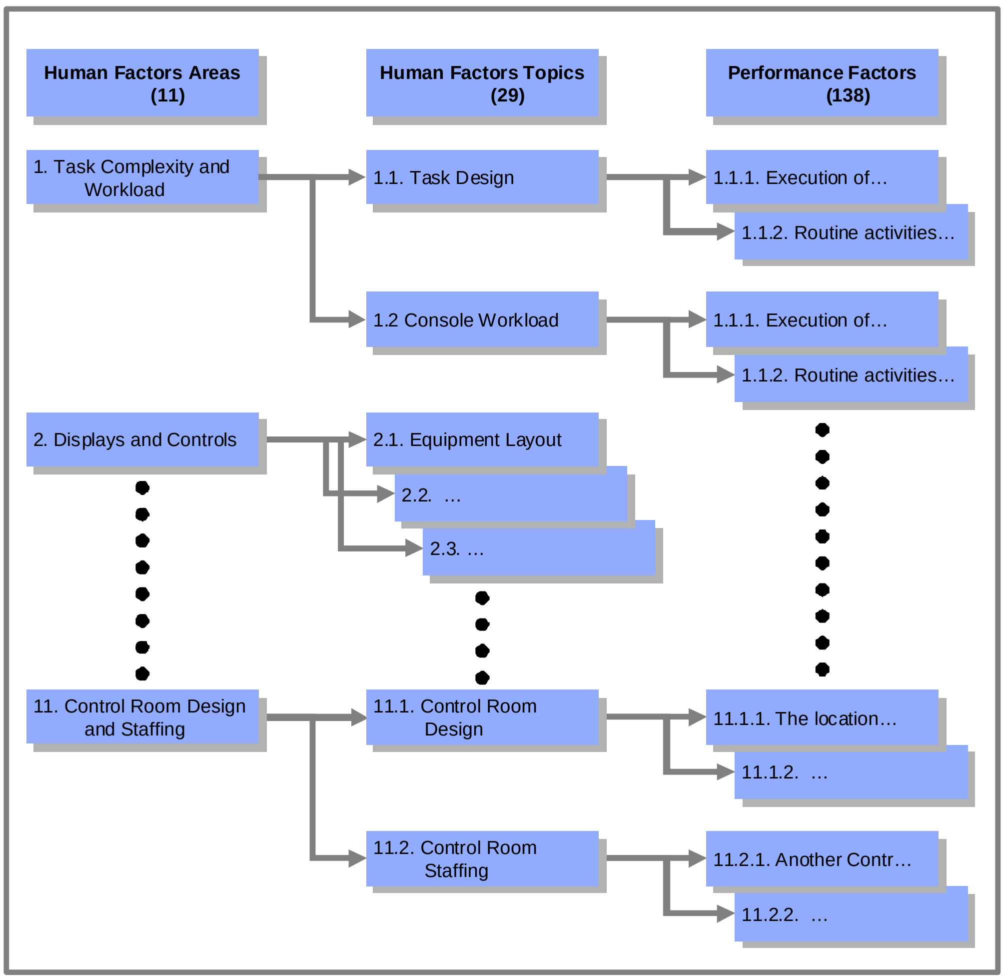


Figure 5. Graphic Depiction of Pipeline Operations Human Factors Taxonomy Organization

The most detailed *Performance Factor* level of the taxonomy includes 138 specific characteristics of the Controller (e.g., experience, fatigue), workspace (e.g., display monitors, lighting), job tools (e.g., batch tracking, SCADA), job design (e.g., control tasks and activities), and other factors that can affect the Controller's ability to effectively monitor and control the pipeline. For example, there are five Performance Factors nested within Human Factors Topic 1.1, including: 1.1.1—Execution of a control action (e.g., open/close valve, start/stop pump, change set point) requires too many steps (e.g., more than three) and 1.1.2—Routine activities (e.g.., line start up, batch cutting, or manifold flushing) are too complex. Appendix C provides a full listing of the taxonomy.

HUMAN FACTORS RISK ASSESSMENT

As noted in the preceding section, the findings from the accident report and Controller interview analyses had a significant influence on the course of the current project. At its inception, the project team had planned to reduce the scope of human factors considered by the final risk assessment process to those that were judged to consistently affect pipeline monitoring and control performance. This plan reflected the intent to develop an effective and efficient process for assessing human factors risks, while avoiding the unnecessary use of resources in assessing areas with minimal risks. However, the results of these analyses suggested that none of the general Human Factors Areas could be excluded from an initial risk assessment at an individual control room without ignoring potentially significant human factors risks. Therefore, the project team revised the initial approach and developed a technique to assess the potential risks associated with a comprehensive set of human factors.

In adopting a strategy of comprehensive consideration of all human factors, an efficient, reliable, and valid means of conducting a broadly-based risk assessment was required. The approach adopted was to develop two complementary rating instruments to obtain estimates from control room staff for each Performance Factor regarding two basic constructs: the *Prevalence* of Performance Factors in the work environment; and the *Risk Likelihood* associated with each Performance Factor if it is present in the operator's pipeline system. Once these two instruments were developed, a method for combining the resulting data into an estimate of the *Risk Level* corresponding to each Performance Factor at an operator's control room was developed. The following discussions describe the development, trial application, and general results corresponding to these three elements of the human factors risk assessment methodology.

CONTROLLER SURVEY

The Controller Survey was one of two instruments developed to collect input for the risk assessment process. The first-generation version of the Controller Survey consisted of several Controller background questions, followed by a series of items corresponding to each Performance Factor in the evolving Human Factors Taxonomy. The background questions provide a means of characterizing the sample of Controllers who complete the survey at a site and are also useful in interpreting responses to survey questions related to Controller training or experience level. The Performance Factor items were designed to obtain two types of input. First, Controllers provided either direct ratings of Prevalence of each Performance Factor in their working environment, or reported that it was either present or absent in their working environment. For the purposes of the current methodology, Prevalence is defined as the estimated level of Controllers' exposure to working conditions associated with a Performance Factor in their control room. Prevalence is seen as influencing risk by increasing Controllers' exposure to conditions that may adversely affect their monitoring and control performance. Second, if a Controller indicated that a Performance Factor was either present or relatively prevalent, they were instructed to provide a brief description of working conditions that they viewed as adversely affecting their performance related to this Performance Factor. Figure 6 provides as example of a survey question, the response format with the Prevalence scale, and the follow-up request for descriptive information.

5.1.2 How often do you use a procedure that does not have adequate technical detail?

☐ Never ☐ Once a year ☐ Few times a year ☐ Once a month ☐ Once a week ☐ Once a day ☐ More than once a day ☐ More than once an hour

If Once a month or more, please explain briefly

Figure 6. Example of Controller Survey Prevalence Response Format

Trial Application of the Controller Survey

The Controller Survey was administered to 222 Controllers. Two hundred and four Controllers from six operators completed an on-line version of the survey and 18 Controllers from one operator completed a paper-and-pencil version of the survey. Battelle researchers supervised all survey administration and strictly maintained Controller response confidentiality. All operators adhered to a sampling criterion that called for a minimum of 80 percent of the Controllers from each console to complete the survey. The survey required a maximum of 2 hours to complete. The trial application of the first-generation Controller Survey provided the opportunity to assess the value of this instrument in obtaining valid, reliable, and discriminable data from Controllers, as discussed below.

Controller Survey Validity. Validity refers to the extent to which an instrument obtains measures that reflect the constructs that are intended to be measured. The Controller survey was developed to obtain Prevalence ratings for individual Performance Factors. A strong case can be made for the *face validity* of the individual Performance Factors that were being rated by Controllers, since they were structured around the analysis of severe pipeline accident analyses, derived from a broad sample of confidential Controller interviews, and underwent an iterative cycle of review and revision by operational and human factors experts. The validity of any frequency or prevalence estimate is limited by any systematic inaccuracies present in such estimates. In general, individuals typically tend to over-estimate infrequent events and under-estimate frequent events. However, such estimates do generally tend to reflect the relative frequency of the events being rated (see Hastie & Dawes, 2001). An independent external metric of Performance Factor Prevalence is not currently available to empirically evaluate the validity of Controllers' survey responses; and such an empirical evaluation of validity was beyond the scope of the current project[1]

Controller Survey Reliability. Reliability refers to the consistency of measures obtained by an instrument. Different indices of reliability have been developed to reflect different aspects of instrument reliability. Test-retest reliability provides an index of the extent that administration of an instrument to similar individuals under similar conditions yields the same responses. The assessment of test-retest reliability was beyond the scope of the present effort, but it is an issue

[1] Relevant external metrics of external validity for the Controller Survey could be an independent observational study of the prevalence of individual Performance Factors or the frequency of incidents analyzed with the use of a compatible Human Factors Taxonomy.

worthy of future consideration. Inter-respondent reliability is an index of the extent that different individuals providing responses to the same instrument under similar circumstances provide comparable responses. This aspect of reliability is important for the utility of an instrument in discriminating between the items being measured, in this case the Prevalence of Performance Factors.

One sample of 24 Controllers from one operator was selected to evaluate the reliability of Controller Survey inter-respondent reliability. These 24 Controllers came from a control room with a typical size and configuration among the participating companies (six consoles in a common space) and had a representative range of Controller experience levels (67% with less than 5 years experience and 33% with more than 5 years experience). For the purposes of reliability analysis, the response categories shown in Figure 6 were given consecutive integer values, beginning with 0 and ending with 7 (i.e., Never = 0, Once a Year = 1, Few Times a Year = 2… More than once an hour = 7). Interquartile ranges of responses were next calculated for each of the 107 Performance Factors in the first-generation Controller Survey that had the same wording and response format as the final version of the Controller Survey. The interquartile range indicates the range of responses between the 25th percentile and 75th percentile rank-order responses.

Table 7 provides the frequency distribution of Prevalence Rating interquartile ranges across the 107 Performance Factors included in this analysis of 24 Controllers' responses from the selected control room. There are no absolute standards regarding the reliability levels corresponding to different interquartile ranges. However, given the current range of Prevalence responses from 0 to 7, suggested reliability levels ranging from 'Very High' for 0.0 – 1.0 to 'Very Low' for greater than 4.0 are provided in Table 7. A review of the Performance Factor frequencies and percentages corresponding to these suggested reliability levels indicates that 45% of the Performance Factors are in the 'High-Very High' levels, 41% in the 'Moderate' level, and 14% in the 'Low-Very Low' levels. Based on the current analysis of one sample of Controllers, Prevalence ratings across Performance Factors obtained with the Controller Survey appear to provide a moderate level of inter-respondent reliability, but a subset of Performance Factors have a low level of reliability. Appendix D provides the Prevalence rating interquartile range statistics for all of the 107 Performance Factors that had the same wording and response format between the first-generation and final versions of the Controller Survey.

Table 7. Distribution of Interquartile Ranges of Prevalence Ratings for 107 Performance Factors by a Sample of 24 Controllers from One Control Room

Prevalence Rating Interquartile Range	Suggested Reliability Level	Performance Factor Frequency	Performance Factor Percentage
0.0 – 1.0	Very High	28	26%
1.5 – 2.0	High	20	19%
2.5 – 3.0	Moderate	44	41%
3.5 -4.0	Low	13	12%
>4.0	Very Low	2	2%

Controller Survey Discriminability. Discriminability refers to the extent that an instrument provides measures that can be used to differentiate between items on the basis of their values. For the purposes of this risk assessment methodology, the objective is to discriminate between Performance Factors on the basis of the Prevalence ratings obtained from the Controller Survey. Discriminability is determined by the combination of the inter-respondent reliability and the range of scores across items. The preceding discussion provides support for the conclusion that the Controller Survey provides a moderately good level of inter-respondent reliability.

Figure 7 presents the range of median Prevalence ratings from the same sample of 24 Controllers used for the reliability analysis. A review of Figure 7 indicates that moderate median Prevalence ratings are relatively frequent; whereas high median ratings are relatively infrequent. This distribution of median Prevalence ratings provides the opportunity to support an adequate level of discriminability between Performance Factors with relatively high median ratings versus those with relatively low or moderate median ratings. This opportunity is supported by the moderate-high inter-respondent reliability levels of the Performance Factors with relatively high median Prevalence ratings – with Performance Factors with median ratings of 4 having an average interquartile range of 2.0, Performance Factors with median ratings of 5 having an average interquartile range of 2.8, and Performance Factors with median ratings of between 6 and 7 having an average interquartile range of 2.1. In summary, the analysis of the Prevalence ratings from this one sample of 24 Controllers from one representative operator suggests that the Controller Survey provides a measure of Performance Factor Prevalence with an adequate level if discriminability.

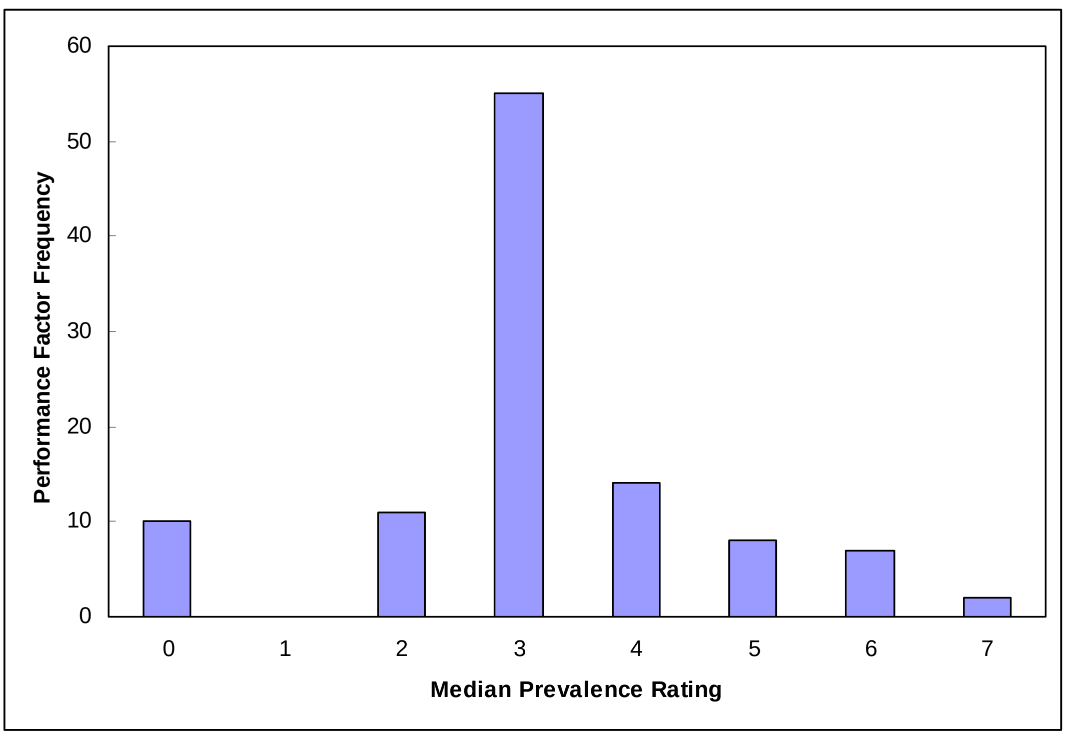


Figure 7. Median Prevalence Rating Frequency Distribution

Final Controller Survey Refinement

The first-generation version of the Controller Survey used for the trial application included both ‘Prevalence’ and ‘Yes/No’ Performance Factor survey items. Prevalence items asked for estimates of the frequency with which Performance Factors were encountered by Controllers. ‘Yes/No’ items asked whether or not Performance Factors were present in the work environment. However, following the final project team definition of the risk assessment methodology, it was determined that ‘Yes/No’ items would be transformed into a ‘Prevalence’ format to allow for a consistent mode of questioning, response scaling, and Risk Level calculation for all Performance Factors. This was accomplished through the conversion of 21 items from a Yes/No format to and Prevalence format and the exclusion two items from the final Risk Level calculation process. Figure 8 provides an example of the Prevalence response alternatives used in the final form of the Controller Survey for Performance Factor 2.1.1.

2.1.1 How often are you unable to display all of the information that you need on the available monitors during *normal* operations?

☐ Never	☐ Once a year	☐ Few times a year	☐ Once a month	☐ Once a week	☐ Once a day	☐ More than once a day	☐ More than once an hour

Figure 8. Standard Controller Survey Prevalence Response Format

In revising several of the ‘Yes/No’ Controller Survey items, a variation of the basic Prevalence response format was adopted for those Performance Factors that address abnormal or emergency working conditions because these questions inherently reflect two separate frequency judgments. Figure 9 provides an emergency event example. These survey items consist of two parts: a first part that obtains an estimate of the Prevalence of emergency events; and a second part that obtains an estimate of the percentage of emergency events in which the Performance Factor in question is present. Additional discussions of how these responses are used to calculate Performance Factor Prevalence and Risk Level scores are provided in the following Risk Level Estimation discussion.

7.2.1a How often do you face an *emergency event*?

☐ Never	☐ Once a year	☐ Few times a year	☐ Once a month	☐ Once a week	☐ Once a day	☐ More than once a day	☐ More than once an hour

7.2.1 In what percentage of emergency events that you have faced were you not adequately trained to respond to the conditions?

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Never	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Figure 9. Two-part Controller Survey Prevalence Format used with Performance Factors that address Abnormal or Emergency Conditions exclusively.

RISK LIKELIHOOD RATING ACTIVITY

The Risk Likelihood rating activity was the second instrument developed to collect operational input for the risk assessment process. Risk Likelihood is defined as the rated likelihood that exposure to the working conditions associated with a Performance Factor will adversely affect Controller job performance and thereby contribute to the occurrence and/or increase in severity of an incident with an unacceptable economic and/or safety consequence. Table 8 shows how this general definition was applied to specify five levels of Risk Likelihood. As a review of these definitions will reveal, the Risk Likelihood Levels in Table 8 are defined primarily on the basis of effects on Controller performance. That is, the primary basis for assigning a Risk Likelihood level to a Performance Factor is the judged likelihood that exposure to specific working conditions will result in sub-optimal Controller performance which, in turn, could be reasonably expected to result in the occurrence and/or increase in severity of an incident with an unacceptable economic and/or safety consequence.

Table 8. Risk Likelihood Levels and Definitions

Risk Likelihood Level	Risk Likelihood Level Definition
Not significant	It is difficult to conceive how this could lead to sub-optimal Controller performance by a conscientious Controller. Includes: ▪ Non-time dependent problems/deficiencies that Controllers can get clarification on by asking, etc, or that they can address during slow periods or when they are not operating a console. ▪ Non-time critical activities that are not an important or regular part of normal operations
Low	Working conditions could plausibly lead to sub-optimal Controller performance, but otherwise this factor is mostly just an actual or potential inconvenience that most Controllers compensate for through training and/or practice. Includes: ▪ General increase in workload from activities that are not time critical and for which Controllers have some control over when to conduct them (e.g., activities that can be easily postponed) ▪ Controllers are aware of problem/deficiencies and have alternative methods for getting information they need
Med	Working conditions represent a situation in which the Controller receives clearly deficient information/support from tools, personnel, etc in a meaningful way. A non-alert Controller could perform sub-optimally, but an alert Controller would likely not be affected, although their activities may be more challenging. Includes: ▪ Unavoidable increases in workload at the same time as important Controller-driven operational activities are ongoing ▪ A novice Controller may be more likely to make errors under these conditions, but not a seasoned Controller
High	Working conditions represent a situation in which the Controller receives clearly deficient information/support from tools, personnel, etc, in a meaningful way, and even an alert/proactive Controller could plausibly perform sub-optimally. ▪ Even seasoned Controllers would not be immune to making errors under these conditions
Very High	Baseline Working conditions are challenging and it is easy to see how a Controller could perform sub-optimally. Controllers must be highly focused on the tasks at hand to avoid performing in a sub-optimal manner. Includes: ▪ Situations where it may be largely outside of the Controller's ability to perform monitoring and control activities in an optimal manner (e.g., key information significantly misrepresents actual conditions in a way that is not apparent to the Controller)

It is important to note that the Risk Likelihood definitions presented in Table 8 do not refer directly to specific definitions or levels of incident consequence. Rather, the definitions reflect the basic assumption that the likelihood of sub-optimal Controller performance can serve as a 'surrogate' measure for the likelihood of an unacceptable incident.

The Risk Likelihood ratings are obtained from operational experts by obtaining their independent judgments regarding the Risk Likelihood level corresponding to each Performance Factor. Each operational expert is provided with a set of cards, each with the definition of one Performance Factor, and the expert is instructed to sort the cards into different groups representing each of the Risk Likelihood levels (defined in Table 8).

Trial Application of the Risk Likelihood Rating Activity

The Risk Likelihood rating activity was administered to a sample of 23 operational experts from the seven participating operator companies. This trial application provided the opportunity to assess the value of the rating activity in obtaining valid, reliable, and discriminable Risk Likelihood ratings from operational experts. As noted in the discussion of the Controller Survey, the underlying validity of the Performance Factors, which make up the separate items being rated, is supported by the process used to define these elements of the taxonomy. Validity of the Risk Likelihood Levels is, likewise, supported by a process that involved the collaborative review and refinement of risk level definitions, which were ultimately linked to concrete effects on Controller performance.

Risk Likelihood Reliability. The trial application of the Risk Likelihood rating activity provided a basis for assessing the inter-respondent reliability of the obtained ratings for all Performance Factors, since the final Performance Factors were used in the trial application of this activity. Table 9 provides the frequency distribution of interquartile ranges across the 138 Performance Factors included in this analysis of 23 operational experts' Risk Likelihood ratings. As in the case of the Controller survey data, there are no absolute standards regarding the reliability levels corresponding to different interquartile ranges. However, given the current range of Risk Level responses from 0 (Not Significant) to 5 (Very High), suggested interquartile reliability levels ranging from 'Very High' for interquartile ranges less than 1.0 to 'Low' for interquartile ranges greater than 2.0 are provided in Table 7.

Table 9. Distribution of Interquartile Ranges of Risk Likelihood Ratings for 138 Performance Factors by a Sample of 23 Operational Experts from Seven Operating Companies

Rating Interquartile Range	Suggested Reliability Level	Performance Factor Frequency	Performance Factor Percentage
<1.0	Very High	9	7%
1.0-1.5	High	82	59%
1.5-2.0	Moderate	43	31%
>2.0	Low	4	3%

A review of the Performance Factor frequencies and percentages corresponding to the suggested reliability levels in Table 7 indicates that 66% of the Performance Factors are in the 'High-Very

High' levels, 31% in the 'Moderate' level, and only 3% in the 'Low' level. Based on the current analysis of a sample of operational experts from seven operating companies, the obtained Risk Likelihood ratings across Performance Factors appear to provide a moderately-high degree of inter-respondent reliability. Appendix E provides a table with Risk Likelihood rating interquartile range statistics for the full set of 138 Performance Factors included in this analysis.

Risk Likelihood Discriminability. As noted in the preceding discussion of the Controller Survey trial application, discriminability is determined by the combination of the inter-respondent reliability and the range of median ratings across Performance Factors. The preceding discussion provides support for the conclusion that the Risk Likelihood rating activity provides a moderately-high level of inter-respondent reliability. Figure 10 presents the range of median Risk Likelihood ratings by the same sample of 23 operational experts used for the reliability analysis. It is important to note that these ratings were obtained across small samples of operational experts from each of the seven participating operators, while the Controller Survey sample used in the current assessment came from a sample of 24 Controllers from one operator. A review of Figure 10 indicates that 'Medium' median Risk Likelihood ratings are very frequent, constituting 70 (51%) of all Performance Factor responses, with the bulk of the remaining Performance Factor median ratings distributed evenly between the 'Low' and 'High' median ratings. This distribution of Risk Likelihood median ratings provides the opportunity for only a modest level of discriminability between Performance Factors, despite the moderately-high level of reliability.

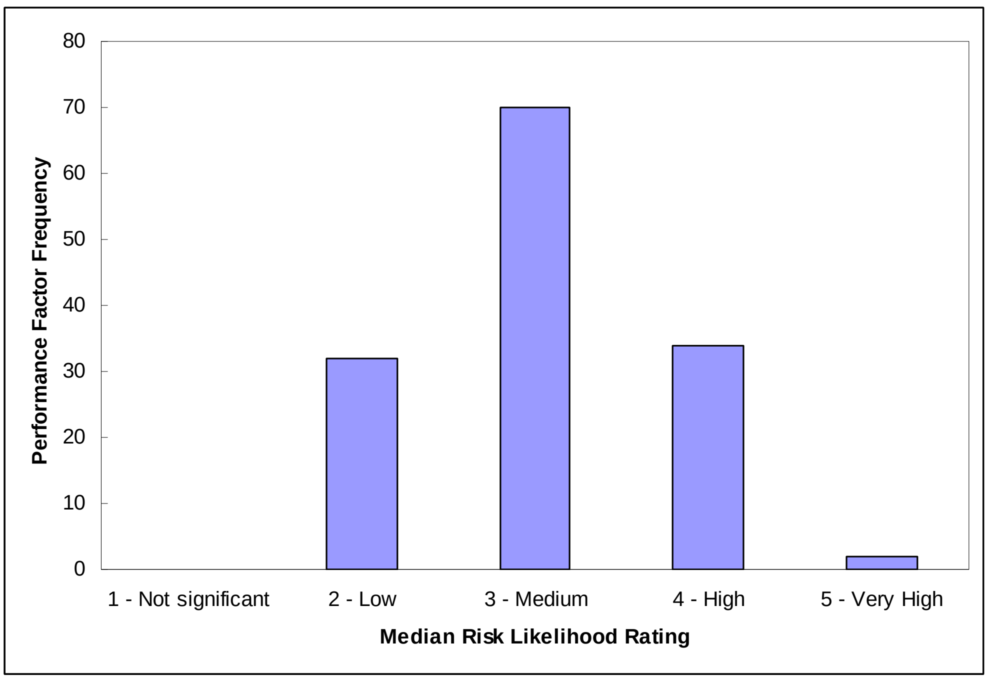


Figure 10. Median Risk Likelihood Rating Frequency Distribution

The relatively tight distribution of Risk Likelihood median ratings depicted in Figure 10 was likely the partial result of a common phenomenon termed 'regression towards the mean'. In a nutshell, 'regression towards the mean' refers to the fact that scores will likely tend toward the mean value of a distribution if there are not systematic factors influencing those values. Because the current sample was drawn from a diverse range of operators, rather than a single operator, it is likely that scores tended to converge towards the central score. This result provides support for the practice recommended in the Guide that each operator obtain their own set of Risk Likelihood ratings to support their risk assessment activities. In this way, the resulting Risk Likelihood ratings will more likely reflect a common set of conditions and operational risks.

Summary of Controller Survey and Risk Likelihood Rating Trial Applications

The conclusions drawn from the preceding review of the validity, reliability, and discriminability assessments for the two data collection instruments is summarized in Table 10.

Table 10. Summary of Controller Survey and Risk Likelihood Validity, Reliability, and Discriminability Assessments

Risk Score	Validity Assessment	Reliability Assessment	Discriminability Assessment
Prevalence	High Face Validity	Moderate Inter-respondent Reliability	Moderate to Good Performance Factor Discriminability
Risk Likelihood	High Face Validity	Moderately High Inter-respondent Reliability	Moderate Performance Factor Discriminability

RISK LEVEL ESTIMATION

The basic goal in developing a Risk Level estimation procedure was to provide an objective and transparent process that could be used by operators to estimate the risks associated with specific human factors in their control room environment. Numerous risk scales were considered in the development of the Risk Level estimation procedure, including economic risk and level of operational consequence. However, after multiple efforts to develop a valid and comprehensible method that was tied to such absolute scales, it was concluded by all members of the project team that a risk scale based on relative frequency and magnitude ratings was more appropriate than an absolute scale, given current limitations in available empirical evidence regarding the causal relationships between individual human factors and pipeline risk levels. A basic approach of using Prevalence and Risk Likelihood ratings for each Performance Factor as an index of Risk Level was adopted, as discussed below.

A Prevalence score was derived from the Prevalence ratings. This score is intended to reflect how often a specific set of working conditions are present in a given control room. The Prevalence score for an individual Performance Factor is calculated as the median value of Controller Survey respondents’ Prevalence ratings for that Performance Factor. The Controller Survey instructs Controllers to provide their Prevalence ratings based on the frequency with which they have encountered working conditions corresponding to an individual Performance Factor during their last year of work in the control room. The individual Prevalence responses are transformed into Prevalence scores to approximate the underlying frequencies for the different Prevalence rating categories, assuming Controllers are working approximately 2,000 hours per year, as summarized in Table 11.

Table 11. Prevalence Response Categories and Scores

Prevalence Response Category	Prevalence Score
Never	0
Once a Year	1
Few Times a Year	2
Once a Month	10
Once a Week	50
Once a Day	200
More than Once a Day	500
More than Once an Hour	2,000

A Risk Likelihood score was derived from the Risk Likelihood ratings in a similar manner as the Prevalence scores. The individual Risk Likelihood rating ratings are transformed into Risk Likelihood scores that both (1) have the same range as the Prevalence scores and (2) have an approximate logarithmic progression of scores, as summarized in Table 12. The range of scores were selected to be comparable to those used for the Prevalence scores, so that Prevalence and Risk Likelihood would be weighted equally in the subsequent Risk Level calculation. The set of Risk Likelihood scores were chosen to approximate a logarithmic scale, since the type of magnitude estimate reflected by these ratings typically reflects an underlying logarithmic scale. As in the case of the Prevalence scores, a Risk Likelihood score for an individual Performance Factor is calculated as the median value of respondents' Risk Likelihood ratings for that Performance Factor.

Table 12. Risk Likelihood Rating Categories and Scores

Risk Likelihood Rating Category	Risk Likelihood Score
Not significant	1
Low	10
Medium	200
High	500
Very High	2,000

Following an iterative process of development, review, and revision, a final set of procedures for calculating the relative Risk Level of Performance Factors and Human Factors Topics was agreed upon by all project team members. A Risk Level score for an individual Performance Factor is calculated by multiplying the Median Prevalence score and the Median Risk Likelihood score for a given Performance Factor, as illustrated in Equation 1 below.

$$\text{Risk Level Score} = \text{Median Prevalence Score} \times \text{Median Risk Likelihood Score}$$

Equation 1. Risk Level Score Calculation

Risk Level scores are computed at both the detailed Performance Factor level and the intermediate Human Factors Topic level. Each Performance Factor Risk Level score is calculated by multiplying a Prevalence score and a Risk Likelihood score corresponding to that Performance Factor[2]. A Risk Level score for a Human Factors Topic is calculated by computing the arithmetic mean (average) across the individual Risk Level scores for all Performance Factors that are included under one Human Factors Topic in the Human Factors Taxonomy.[3]

Risk Level Calculation Trial Application

The Risk Level score calculation procedure was applied in a trial application using the trial Controller Survey Prevalence data and Risk Likelihood data obtained from the seven participating pipeline operating companies. Risk Level scores were calculated for each company, based on individual company Controller Survey Prevalence scores, and the set of Risk Likelihood scores based on the combined ratings of operational experts from the seven participating companies. In addition, a set of Risk Level scores based on median Prevalence and Risk Likelihood scores across participating operators were calculated.

The validity and reliability of the resulting Risk Level scores are fundamentally determined by the characteristics of the component Prevalence and Risk Likelihood scores. As summarized in Table 10, both Prevalence and Risk Likelihood scores were judged to have high face validity. As discussed above, the process used in developing the Performance Factors and Human Factors Topics was based on a broad literature review, analysis of severe pipeline accident investigations, and an extensive review of first-hand Controller reports. This process supports the face validity of the Performance Factors that were scored. In addition, participating operators provided extensive input to the Risk Level calculation process in order to ensure that it was consistent with their company’s risk assessment processes. Then, participating operators were asked to review their individual Risk Level rankings to see if they could identify any anomalous results. No anomalies were identified by operators, so this was taken as additional evidence for the underlying validity of the Risk Level estimation process. Prevalence scores were judged to have moderate reliability; and Risk Likelihood scores were judged to have moderately high

---

[2] Prevalence scores for Performance Factors that refer to abnormal or emergency conditional are calculated by multiplying the Prevalence score (see Table 10) for abnormal or emergency conditions by the median percentage rating for the Performance Factor (see Figure 9).

[3] Appendix C specifies the Performance Factors included in the Risk Level calculation for each Human Factors Topic.

reliability. Considered together, it would be reasonable to expect the Risk Level scores to have high face validity and at least moderate reliability.

In considering the discriminability of Risk Level scores it is important to consider the objective of the current effort, which is to identify those human factors – reflected by both individual Performance Factors and Human Factors Topics – that 'stand out' as being associated with relatively higher risk levels. Therefore, a resulting scale that provides a high level of discriminability between high- and moderate-risk levels will be most useful. Table 13 provides the Human Factors Topic Risk Level scores and rankings obtained from the trial application of the Controller Survey and Risk Likelihood rating activity at all seven participating companies. Note that Prevalence score values for Yes/No items in this table were based on a transformation algorithm for the trial version of the Controller Survey[4]; whereas the final form of the Survey does not have any Yes/No items[5]. Review of this table reveals that the highest-ranking topic has a Risk Level score that is several orders of magnitude greater than any other topic, that the next three topics have comparable Risk Level scores, that there is a relatively steady decline in Risk Level scores through the remaining top-nine topics, and then that there are clusters of topics with comparable Risk Level scores. Taken as a whole, this preliminary result suggests good discriminability of the Risk Levels between those Performance Factors that would be of the greatest concern.

---

[4] For the purposes of computing preliminary Prevalence scores from Yes/No Controller Survey item data, the following transformation based on the percentage of Controller Survey respondents who responded 'Yes' to an item was used: 0-5% Yes = 0 Prevalence score; 6-10% Yes = 1 Prevalence score; 11-15% Yes = 2 Prevalence score; 16-20% Yes = 10 Prevalence score; 21-25% Yes = 50 Prevalence score; 26-30% Yes = 200 Prevalence score; 31-40% Yes = 500 Prevalence score; >41% Yes = 1,000 Prevalence score.

[5] It should be recognized that the Yes/No item Prevalence score transformations used in the present analysis complicates the interpretation of the resulting Risk Level rankings for the Performance Factors. However, the process by which the scores are obtained can be defended as having high face value; and the resulting Risk Level scores were judged by operational experts to be valid. As discussed previously, this transformation of Yes/No Prevalence responses will not be necessary in future applications of the Controller Survey and Risk Likelihood calculations. Therefore, it is reasonable to expect that future application of this methodology using the revised Controller Survey that incorporates only Prevalence response scales will result in Risk Level rankings that also have a high level of validity.

Table 13. Risk Level Score and Ranking by Human Factors Topic obtained from the Trial Application across all Companies

HF Topic #	HF Topic Description	Risk Level Score	Risk Level Ranking
‡8.1	Abnormal Situation Task Assignments	220,000	1
†9.4	Alertness Management Practices*	10,350	2
1.1	Task Design	10,000	3
†6.5	Nuisance Alarms	10,000	3
†7.1	Pipeline Fundamentals Knowledge and Field Exposure	2,500	5
9.1	Controller Fatigue	2,000	6
†11.1	Control Room Design	1,525	7
4.1	Operational Information Accuracy and Availability	1,000	8
3.3	Schedule Communications	700	9
6.1	Alarm Availability and Accuracy	500	10
†6.4	Alarm Access and Acknowledgement	500	10
1.2	Console Workload	400	12
2.2	SCADA Information Access and Layout	400	12
3.2	Control Center Communications	400	12
3.4	Field Personnel Communications	400	12
5.1	Job Procedure Design	400	12
9.2	Controller Schedule and Rest	400	12
11.2	Control Room Staffing	400	12
5.2	Job Procedure Availability	350	19
5.3	Job Procedure Accuracy and Completeness	350	19
3.1	Shift Hand-off Procedures	300	21
‡7.2	Emergency Response Training	250	22
†6.3	Alarm Interpretation	200	23
†2.1	Equipment Layout and Workstation Design	110	24
9.3	Slow Work Periods	105	25
8.2	Control Room Distractions	20	26
10.1	Automated Operations	10	27
2.3	SCADA Information Content, Coding, and Presentation	0	28
6.2	Alarm Displays and Presentation	0	28

* One Performance Factor (9.4.1) Prevalence score in this Human Factors Topic was estimated on the basis of the Prevalence score for a similar Performance Factor. (9.1.2).

‡ Topic consisted exclusively of Yes/No items

† Topic consisted of some Yes/No items

Table 14 provides the Performance Factor Risk Level scores for the 19 highest-ranking Performance Factors, based on the trial application of the Controller Survey and Risk Likelihood rating activity and resulting scores combined across participating operators. Again, the previously-discussed transformation was used to calculate Prevalence scores for Yes/No Controller Survey items. Review of this table indicates that there are several groupings of Performance Factor Risk Level scores, with the top-seven scores being especially noteworthy. However, it is also important to note that six of these seven Performance Factors were originally Yes/No items, suggesting that these results could represent an artifact of the Yes/No Prevalence scoring algorithm. The complete version of Table 14 that includes all Performance Factors is provided in Appendix F.

Table 14. Prevalence Score, Risk Likelihood Score, Risk Level Score, and Risk Level Ranking for the 20 Highest-Ranking Performance Factors based on the Trial Application across Participating Operators

PF ID	Prevalence Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
‡6.5.1	The number of nuisance alarms limits the ability to quickly identify potentially important alarms	2000	500	1000000	1
‡6.5.3	Monitoring and control activities are disrupted by unnecessary information alarms, or notifications being displayed on the alarm screen (e.g., action started, action completed, etc)	2000	200	400000	2
‡8.1.1	Controllers are distracted in their response to *abnormal* events by non-critical, ongoing duties	2000	200	400000	2
‡8.1.3	Controllers are distracted in their response to *abnormal* events by the need to continue to monitor and control unrelated, ongoing operations	2000	200	400000	2
‡7.1.7	Controllers are not provided adequate training before the introduction of a new pipeline	500	500	250000	5
1.1.3	Controllers make errors in performing manual calculations that are used directly as an input to operational activities	500	350	175000	6
‡7.1.1	Controller training does not adequately prepare Controllers to respond to all the situations that they are likely to encounter	200	500	100000	7
1.2.2	Excessive telephone activity interferes with monitoring and control operations	200	200	40000	8
‡6.4.4	Previously acknowledged alarms are not immediately available (i.e., it takes two or more steps, screens, or keystrokes to access previously acknowledged alarms)	200	200	40000	8
‡8.1.2	Controllers are distracted in their response to *abnormal* events by the need to provide required notifications	200	200	40000	8
‡11.1.1	The location of break facilities keeps Controllers away from their console too long	200	105	21000	11
‡9.4.2	Controllers do not notify management when they report to work without adequate rest	2000	10	20000	12
1.1.2	Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex	50	200	10000	13
1.1.5	Some operations have a very small margin for error	50	200	10000	13
1.2.1	Two or more control operations (e.g., line switches) must be done at the same time	50	200	10000	13
‡6.5.4	Too many nuisance alarms are caused by equipment that is waiting to be fixed	50	200	10000	13
4.1.1	SCADA data from field instruments (meters, gauges, etc) are inaccurate	10	500	5000	17
‡7.1.3	Controllers are not provided adequate training about hydraulics	10	350	3500	18
‡7.1.5	Controllers are not adequately trained on specific console operations prior to working alone	2	1250	2500	19

‡ Yes/No

CONTROL ROOM OPERATIONAL REVIEWS

Control room operational reviews represent a transition between the risk assessment and mitigation selection procedures in the present methodology. The Controller Survey, Risk Likelihood rating, and Risk Level estimation procedures provide an empirically-based means of assessing the relative risks associated with pre-defined human factors in an operator's control room. However, informed risk assessment, mitigation selection, and mitigation development also requires an in-depth understanding of both (1) the working conditions that are adversely affecting Controller performance; and (2) the most appropriate mitigations to address the potential risks associated with these conditions. The control room operational review procedures were developed to provide operators with procedures and guidance for conducting such focused reviews. This section describes the development and trial application of first-generation operational review materials, feedback obtained from the industry participants following trial application, and the refinement of the operational review materials.

OPERATIONAL REVIEW PROCEDURES DEVELOPMENT AND TRIAL APPLICATION

The trial application of the first-generation operational reviews was conducted immediately following the development and trial application of the Controller Survey; but before the final development of Risk Likelihood rating and Risk Level estimation procedures. Participating operators were provided a rank-ordered list of Performance Factors and Human Factors Topics that were estimated to be associated with relatively high levels of potential human factors risk (based on a preliminary risk level estimation procedure) and asked to select a subset of Performance Factors for trial application of the preliminary operational review procedures. The trial operational review procedures included procedures for: (1) reviewing the Controller Survey data to select topics for review; (2) selecting applicable operational review activities for each topic from alternative activities (incident analysis, interviews, work observation, and materials review); (3) refining risk estimates on the basis of Prevalence and consequence considerations; and (4) summarizing findings to support the selection of human factors for mitigation development.

The first-generation operational review procedures were applied by six operators in eight different control rooms, including two smaller control rooms managed by operators of larger control rooms. Feedback surveys were provided to participants to aid in the structured review and refinement of the first-generation operational review materials. Four operators completed and submitted a copy of the feedback survey[6]. Among the operators who completed a feedback survey, the first-generation operational review procedures were applied to the review of 35 different Performance Factors a total of 66 separate times.

Lessons learned from the trial application of the first-generation operational review procedures were abstracted from the completed feedback surveys, as well as from more general feedback provided by industry participants. These lessons learned served as the basis for developing a set of operational review procedure revision strategies. Table 15 provides a summary of the lessons learned from the trial application of the first-generation operational review procedures and the

[6] Two operators completed operational reviews for two control centers and in one of these cases, the operator also provided multiple feedback forms; but only one form was used from that operator to avoid overemphasizing their feedback in the summary.

revision strategy corresponding to each lesson learned. A detailed summary of the feedback survey findings is provided in Appendix G.

Table 15. First-Generation Operational Review Trial Applications Lesson Learned and Corresponding Revision Strategy

Lesson Learned from Pilot Application	Revision Strategy
There is too much redundancy in operational review activities when they address individual Performance Factors, rather than Human Factors Topics.	Shift the focus of operational reviews to the Human Factors Topic level.
Instructions were too complicated and difficult to follow.	Simplify instructions and obtain additional feedback from users.
There was too much detail regarding the Controller Survey analysis and results.	Simplify the Controller Survey analysis and results discussion (this will be shifted to the risk assessment step) and emphasize the rank-order Risk Level results.
The purpose of individual operational review sections and activities was not totally clear, which made scoping and planning difficult.	Simplify, explain the purpose, and define the procedures corresponding to each of the individual operational review steps and activities.
The risk analysis procedures in the operational reviews were difficult to understand and apply and appear to have limited validity.	Eliminate the additional risk estimation and analysis activities in the operational reviews and shift risk assessment to a prior methodological step.
The operational review guidance specific to individual Performance Factors and Human Factors Topics' was useful and even more detail could be valuable.	Focus the specific guidance at the Human Factors Topic level; and refine and elaborate, as appropriate.
Including Controller comments in the Controller Survey analysis supported interpretation and operational review preparation.	Continue to provide Controller comments in the survey analysis reports.
The operational review scoping worksheet was judged to be useful for planning.	Continue the scoping worksheet, with appropriate refinements.
Company accident and incident reviews would be more appropriate if these procedures were consistent with the current project's human factors taxonomy.	Identify the potential value of developing a standardized incident analysis procedure consistent with the current taxonomy in the final technical report.
The interview worksheets could be revised so that they more directly supported conducting interviews.	Review and revise interview worksheets as appropriate in paper format for the current effort.
The observational activities had limited applicability, due to the time that would be required to observe most activities during a normal work period.	Maintain observational activities, since they are applicable for selected topics; but highlight the limited applicability of this activity.
The observation worksheet was relevant and well organized for those cases where observations were a feasible activity.	Maintain the worksheet, but review for potential refinements and highlight the limited applicability of this activity.
The materials review worksheet received generally positive feedback, but one operator indicated that the corresponding instructions were too vague.	Maintain the materials review worksheet, but review the sections and instructions for potential refinements.
There was no place to identify potential mitigations in the materials review worksheet.	Ensure that potential mitigations can be identified in a separate section of all review activity worksheets.
In the Summary Sheet, the *general factors and constraints* section was too general and had limited value -- specifics are more relevant here.	Eliminate this topic throughout the operational review procedures.
Repetition of effort should be avoided in completing the Summary Sheet – this is information that is already documented in the other forms	The purpose of this worksheet is to provide the comprehensive documentation of completed activities. Review and minimize potential duplications of effort; but do not eliminate the summary and integration of findings step.

OPERATIONAL REVIEW PROCEDURES REFINEMENT

The lessons learned and revision strategies summarized in Table 15 were applied in the development of a revised set of operational review procedures and supporting materials. These procedures were divided into the two steps in the broader human factors risk assessment and management methodology of Step 5—*Select Operational Review Topics* and Step 6—*Conduct and Summarize Operational Reviews*. Table 16 summarizes the revised set of operational review sub-steps that comprise each of these two steps and the supporting materials developed for each sub-step.

Table 16. Summary of Revised Operational Review Sub-steps and Supporting Materials

Revised Operational Review Sub-step	Supporting Materials
5.1 Review Human Factors Topic Risk Level Rankings	• Sub-step 5.1 guidance • Human Factors Risk Level Ranking Table
5.2 Review High-Risk Performance Factors	• Sub-step 5.2 guidance • Performance Factor Prevalence Score, Risk Likelihood Score, Risk Level Score, and Risk Level Ranking Table
5.3 Select Operational Review Topics	• Sub-step 5.3 guidance • Step 5 Operational Review Topic Selection Summary Sheet and instructions
6.1 Define Scope and Plan for Operational Review	• Sub-step 6.1 guidance • Sub-step 6.1 Scoping Worksheet and instructions
6.2 Conduct Information Collection Activities • Accident, Incident, and Near-Incident Reviews • Interviews • Observations • Materials Review	• Sub-step 6.2 general guidance • Accident, Incident, and Near-incident Report Worksheet and instructions • Interview Worksheet and instructions • Observation Worksheet and instructions • Materials Review Worksheet and instructions • Detailed Operational Review guidance
6.3 Summarize Operational Reviews	• Sub-step 6.3 guidance • Sub-step 6.3 Operational Review Summary Sheet and instructions

Figure 11 depicts a basic two-page format that was developed and applied to prepare the detailed operational review guidance for each of the 29 individual Human Factors Topics included in the Human Factors Taxonomy. Definitions for the pertinent Human Factors Topic and Performance Factors nested within that topic are provided in the first two sections of the summary. The next three sections provide brief descriptions of specific interview topics, observation activities, and materials review topics that may be applicable for an operator's operational review. One example from each of these sections for Human Factors Topic 1.1, Task Design, are: Interview—Controller interview to identify field equipment that requires special procedures; Observation—observation of expert versus novice Controller performance of common procedures; and Materials Review—Review of SCADA control 'dialogue box' design inconsistencies across similar equipment. The final section of the standard format is a repeat of the summary material for potential mitigations (described in the following report section), which indicates the level of evidence supporting the applicability of potential mitigations for reducing human factors risks associated with each Performance Factor.

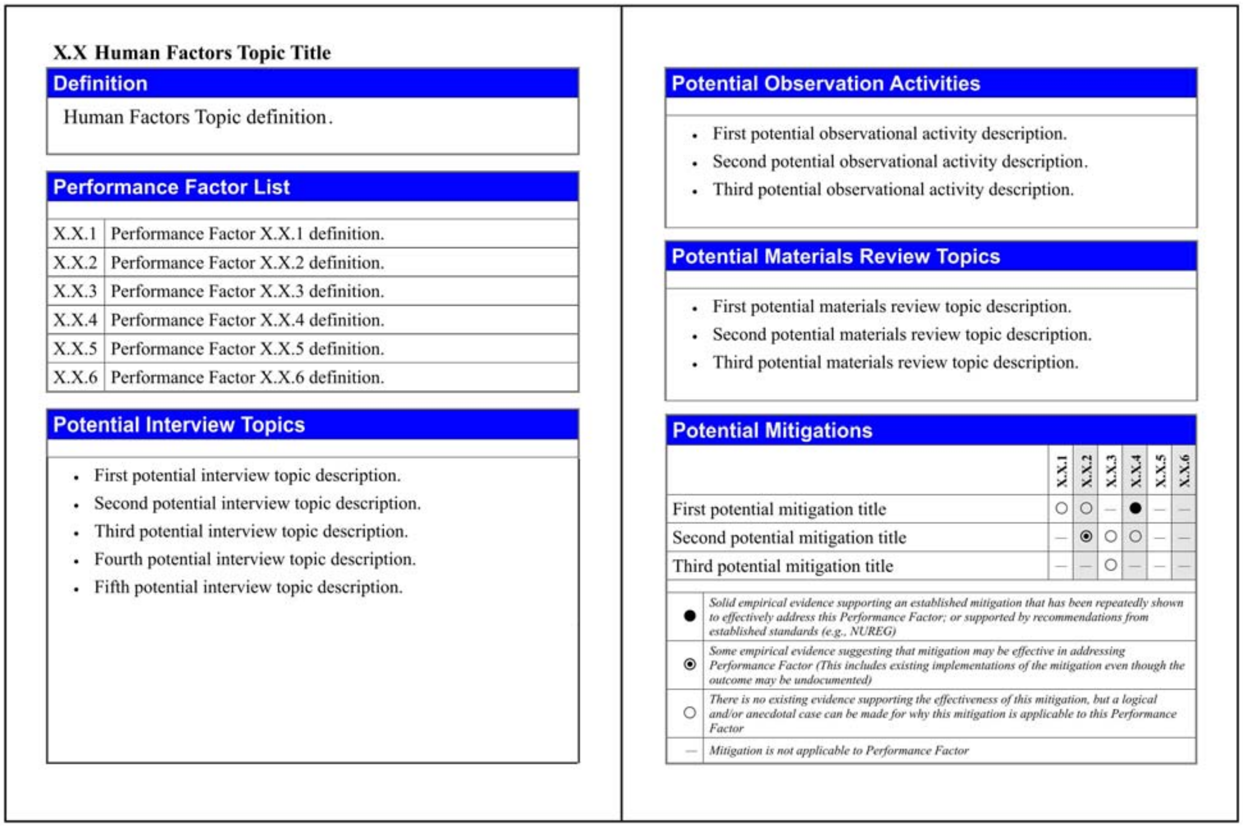


Figure 11. Summary of Detailed Operational Review Guidance Two-Page Format

As is the case for the other steps in the overall risk assessment and management process, the general guidance and worksheets corresponding to each sub-step were incorporated into a draft *Liquid Pipeline Operator's Control Room Human Factors Risk Management Guide* that was prepared for industry review and comment. Following a cycle of review and revision, the final materials were incorporated into the final Guide.

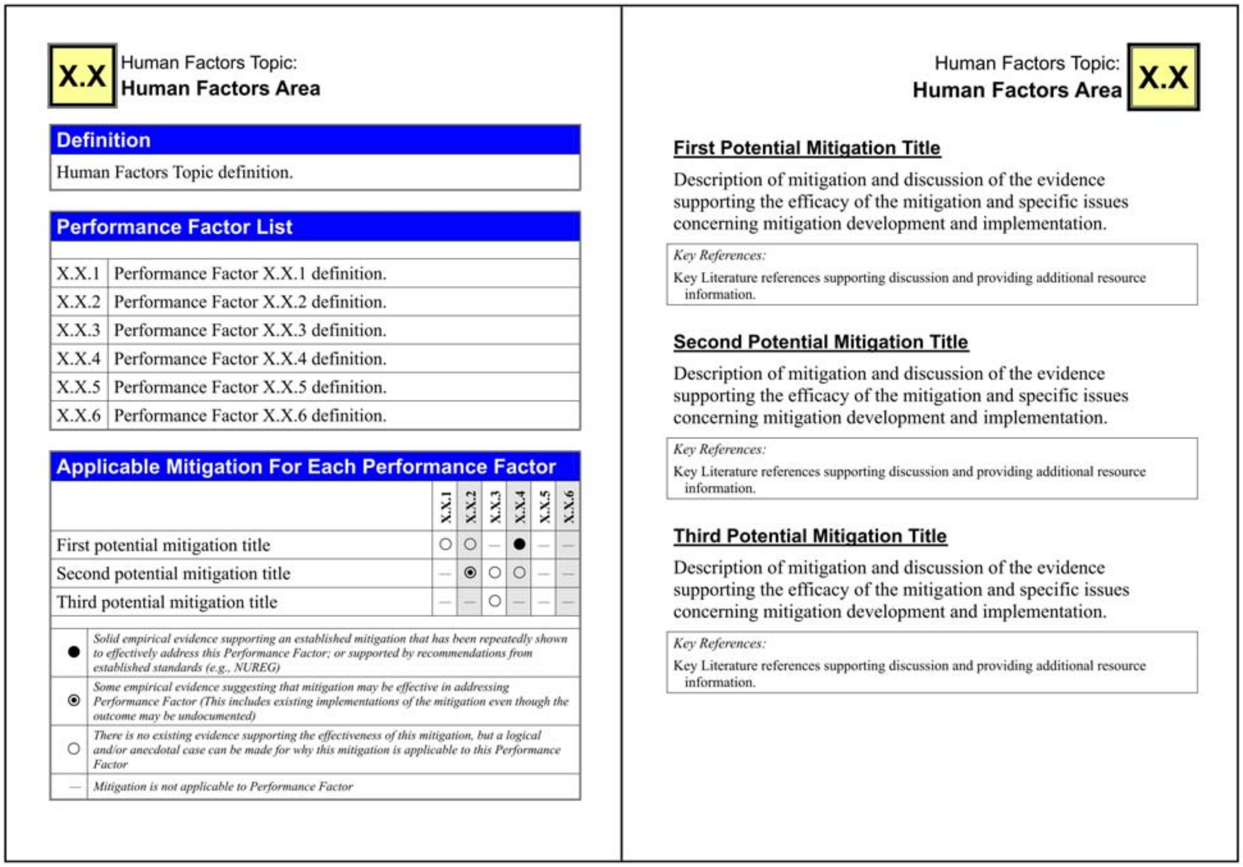
RISK MITIGATION SELECTION AND DEVELOPMENT

Following an operator's completion of operational reviews, a cycle of human factors risk assessment and management steps is completed with the two steps of Step 7—*Develop a Risk Mitigation Strategy* and Step 8—*Develop and Implement Risk Mitigations*. There are numerous factors that will influence the performance of these two steps which cannot be determined in advance of an individual effort, including emerging operational safety concerns, new operational procedures and technologies, current internal organizational priorities, and emerging regulatory emphasis. Because the factors influencing these steps cannot be well defined in advance, the two steps were developed with less strictly-defined procedures than those of the preceding steps. Rather, a general framework for conducting these two steps was developed and summaries of alternative mitigations and relevant empirical findings were provided for operators' reference in completing the steps. Following is a summary of the mitigation descriptions development and the final mitigation selection and development procedures.

MITIGATION DESCRIPTIONS DEVELOPMENT

The literature searches and reviews summarized earlier in this report were relied upon heavily by the Battelle project researchers to identify and define relevant mitigations; and then summarize the efficacy of mitigations. Individual source documents were classified on the basis of the relevant Human Factors Area. Then, research team members reviewed each source document to identify and summarize the pertinent mitigation information. The obtained information was integrated into 86 separate mitigation descriptions and organized into 29 sections that provide detailed descriptions of mitigations relevant to each Human Factors Topic.

Figure 12 depicts the multi-page format developed and applied in preparing the 29 sets of detailed mitigation descriptions. The left-hand page of each description identifies the Human Factors Topic and nested Performance Factors. Then, the applicability and efficacy of each mitigation is summarized in a separate table in the bottom-half of this page. For the purposes of summarizing the available mitigation efficacy evidence, four categories and codes were developed and applied, as summarized in Figure 13. The evidence supporting the efficacy of each mitigation to reduce the risks associated with an individual Performance Factor was categorized as representing: (1) solid empirical evidence; (2) some empirical evidence; (3) no empirical evidence but logical or anecdotal support; or (4) no evidence regarding its applicability or efficacy. Battelle researchers made preliminary independent efficacy classifications based on available literature, reviewed one another's judgments, and then agreed upon a final efficacy classification for each mitigation.



X.X Human Factors Topic:
Human Factors Area

Definition

Human Factors Topic definition.

Performance Factor List

X.X.1	Performance Factor X.X.1 definition.
X.X.2	Performance Factor X.X.2 definition.
X.X.3	Performance Factor X.X.3 definition.
X.X.4	Performance Factor X.X.4 definition.
X.X.5	Performance Factor X.X.5 definition.
X.X.6	Performance Factor X.X.6 definition.

Applicable Mitigation For Each Performance Factor

	X.X.1	X.X.2	X.X.3	X.X.4	X.X.5	X.X.6
First potential mitigation title	○	○	—	●	—	—
Second potential mitigation title	—	◉	○	○	—	—
Third potential mitigation title	—	—	○	—	—	—

●	*Solid empirical evidence supporting an established mitigation that has been repeatedly shown to effectively address this Performance Factor; or supported by recommendations from established standards (e.g., NUREG)*
◉	*Some empirical evidence suggesting that mitigation may be effective in addressing Performance Factor (This includes existing implementations of the mitigation even though the outcome may be undocumented)*
○	*There is no existing evidence supporting the effectiveness of this mitigation, but a logical and/or anecdotal case can be made for why this mitigation is applicable to this Performance Factor*
—	*Mitigation is not applicable to Performance Factor*

Human Factors Topic: X.X
Human Factors Area

First Potential Mitigation Title

Description of mitigation and discussion of the evidence supporting the efficacy of the mitigation and specific issues concerning mitigation development and implementation.

Key References:
Key Literature references supporting discussion and providing additional resource information.

Second Potential Mitigation Title

Description of mitigation and discussion of the evidence supporting the efficacy of the mitigation and specific issues concerning mitigation development and implementation.

Key References:
Key Literature references supporting discussion and providing additional resource information.

Third Potential Mitigation Title

Description of mitigation and discussion of the evidence supporting the efficacy of the mitigation and specific issues concerning mitigation development and implementation.

Key References:
Key Literature references supporting discussion and providing additional resource information.

Figure 12. Summary of Detailed Operational Review Guidance Format and Content

●	*Solid empirical evidence supporting an established mitigation that has been repeatedly shown to effectively address this Performance Factor; or supported by recommendations from established standards (e.g., NUREG)*
◉	*Some empirical evidence suggesting that mitigation may be effective in addressing Performance Factor (this includes existing implementations of the mitigation even though the outcome may be undocumented)*
○	*There is no existing evidence supporting the effectiveness of this mitigation, but a logical and/or anecdotal case can be made for why this mitigation is applicable to this Performance Factor*
—	*Mitigation is not applicable to Performance Factor*

Figure 13. Mitigation Efficacy Evidence Categories and Codes

The initial set of mitigation descriptions were assembled and submitted to industry project team members for their review and comment. Review comments included the suggested addition of several new mitigations that had been used by participants, the suggested combination of a few mitigations that were seen as too focused, and the suggested elaboration of selected mitigation descriptions. The Battelle researchers addressed all industry review comments and incorporated a revised set of detailed mitigation descriptions in the draft *Liquid Pipeline Operator's Control Room Human Factors Risk Management Guide* that was prepared for further industry review and comment. Following a final cycle of review and revision, the final mitigation descriptions were incorporated into the final Guide.

MITIGATION STRATEGY DEVELOPMENT PROCEDURES

The initial draft procedures and guidance to support mitigation strategy development were submitted to the industry project team for review and comment. These draft procedures incorporated a relatively well-defined process for selecting mitigations, in spite of the research team's recognition that a broad range of factors could influence mitigation selection. Resulting feedback from the industry project team members was consistent – that a general set of steps and procedures, along with standard documentation, would be useful; but that an approach that was too detailed and prescriptive would have limited applicability across the range of organizations that would apply the procedures. Additional factors arguing against specific mitigation strategy development procedures included unanticipated changes in regulatory emphasis, differing organizational priorities, future technical advances, and changes in operational practices.

Industry review comments and suggestions were incorporated into a revised set of procedures and guidance summarized in Table 17 for the two steps of Step 7—*Develop a Risk Mitigation Strategy* and Step 8—*Develop and Implement Risk Mitigations*.

Table 17. Summary of Revised Operational Review Sub-steps and Supporting Materials

Revised Operational Review Sub-step	Supporting Materials
7.1 Identify and Assess Alternative Mitigations for each Human Factors Topic	• Sub-step 7.1 general guidance • Detailed Mitigation Descriptions • Alternative Mitigation Assessment Worksheet and instructions
7.2 Prioritize Mitigations for Development and Implementation	• Sub-step 7.2 general guidance • Mitigation Strategy Summary Sheet and instructions
8.1 Establish a Mitigation Plan	• Sub-step 8.1 guidance • Mitigation Development Plan Worksheet and instructions
8.2 Develop and Refine Mitigations	• Sub-step 8.2 general guidance
8.3 Obtain User Feedback	• Sub-step 8.3 general guidance
8.4 Implement Mitigations	• Sub-step 8.4 general guidance

It is important to recognize that the entire set of risk mitigation selection and development procedures underwent successive cycles of industry review and refinement, but did not undergo any trial application. This development approach was adopted for two basic reasons. First, mitigation development would require a substantial level of resources that could not be committed during the initial stages of this project. Second, as noted earlier in this section, these procedures are quite general, since there are many factors that will influence the process that can not be anticipated or which are specific to an operator. With such general procedures, there was less of a need for trial application and refinement. However, it is recognized that future industry implementation of these procedures could provide an opportunity to obtain feedback and implement refinements.

CONCLUSIONS AND RECOMMENDATIONS

The current project represents a first effort in several respects. Not only was this the first comprehensive review of human factors in pipeline monitoring and control operations; but it was also the first attempt to develop a comprehensive methodology that could be applied by pipeline operators in assessing and managing human factors risks in their operations. The current effort included a substantial level of trial application of procedures, as well as industry review and refinement; but that refinement could only be carried so far. The following conclusions and recommendations discuss the extent that the project objectives were accomplished, limitations in the applicability of the developed methodology and obtained results, and suggested future efforts to improve and implement the products of this project.

ACCOMPLISHMENT OF PROJECT OBJECTIVES

The Background and Introduction section of this report identifies three major project objectives. Each of these objectives is re-stated below, along with the project team's conclusions regarding the extent to which each objective was accomplished.

Understand the human factors that affect pipeline Controllers' abilities to safely and efficiently monitor and control pipeline operations in the control room. The project team conducted a comprehensive analysis of publicly available literature pertinent to human factors and process control operational safety and efficiency, NTSB severe pipeline accident investigations, and first-hand reports from Controllers regarding factors contributing to past incidents and general operational challenges. These analyses led to the development of a *Liquid Pipeline Control Room Human Factors Taxonomy* that is intended to provide a comprehensive, yet detailed summary of factors that can adversely affect the safety and efficiency of pipeline Controller performance. The overall organization of this taxonomy is consistent with existing human factors taxonomies that have been developed for application in other process control industries. In addition, the taxonomy underwent extensive review by operational experts to ensure that the final taxonomy is comprehensive, valid, and comprehensible. The project team is confident that the resulting taxonomy accurately reflects the full range of human factors that can affect pipeline Controllers' abilities to safely and efficiently monitor and control liquid pipeline operations in the control room. However, there are some concerns regarding the applicability of the taxonomy to other industry segments, as discussed later in this section.

Develop procedures for use by pipeline operators to assess the relative risk levels associated with a full range of human factors in their control room operations. Several products of this project were developed to provide pipeline operators with tools and procedures that they could apply in assessing the risk levels associated with a full range of human factors in their control room operations. The *Controller Survey*, *Risk Likelihood* rating activity, and *Risk Level* calculation procedure provide operators with a set of valid and reliable tools and procedures that can be used to prioritize the entire set of human factors included in the taxonomy based on the estimated relative human factors risks in their control rooms. These tools and procedures provide a well-defined, transparent process that can be documented and reviewed to ensure that a thorough, comprehensive, and objective analysis of potential risks is conducted; and to provide a basis for comparisons across time in order to evaluate the effectiveness of risk mitigation strategies and update risk management priorities.

Develop a guide that liquid pipeline operators can use to select, develop, and implement cost-effective mitigations to reduce operational risks associated with control room human factors. An eight-step procedure was defined to provide liquid pipeline operators with a comprehensive framework for assessing human factors risks in their control rooms; and then selecting, developing, and implementing cost-effective mitigations to reduce current risk levels. This framework provided the basis for the development of a guide, consisting of an integrated set of tools, procedures, instructions, and guidance for use by operators. In addition to the Controller Survey, Risk Likelihood rating activity, and Risk Level Calculation tools discussed above, significant components of the Guide include detailed operational review guidance and potential mitigation descriptions. Extensive trial applications of a first-generation version of the operational review procedures and guidance provided a useful basis for subsequent refinement of these procedures. Trial application of the mitigation selection, development, and implementation procedures was beyond the scope of the current effort. These latter materials did undergo substantial industry review and refinement; but it is likely that future application will provide useful input for further refinement.

APPLICABILITY OF METHODOLOGY TO OTHER INDUSTRY SEGMENTS

The industry team that supported this project represented larger operators who primarily transport liquid products. For the purposes of the current discussion, a 'large-scale' operator is being defined as one with five or more separate consoles that are operated on a 24-hour schedule in their control room. Industry team members did include two operators who also managed the operations of smaller liquid pipeline control rooms, providing a partial basis for assessing the applicability of the methodology in those settings. In addition, some of our participating operators transported some gas products; and the research team did have the opportunity to conduct a limited set of observations and interviews with one gas distribution operator. However, for the most part, the issues and concerns of our industry team would best be characterized as representing those of relatively large liquid operators. So, caution should be taken when considering application of the current methodology to small- or medium-scale liquid pipeline operators; or gas pipeline operations. Some specific methodology application issues are considered below.

Small-, Medium-, and Large-Scale Liquid Operations

The most fundamental concern with respect to the applicability of the current methodology is the applicability of the Human Factors Taxonomy. This taxonomy serves as the technical reference for the Controller Survey, Risk Likelihood ratings, operational review topics, and mitigation descriptions. If the taxonomy is not applicable to a segment of pipeline operators, then the specific procedures that refer to the taxonomy will not be directly applicable. There is good reason to have a high level of confidence that this taxonomy will be applicable to other liquid operators, since there are many similarities in the operations of small-, medium-, and large-scale liquid pipeline operations. However, without an adequate sampling of small- and medium-scale liquid pipeline operators, the project team has very limited data on which to conclude that the taxonomy could be applied to smaller-scale operators. In addition, appropriate mitigation strategies may differ between operators of different scales.

Liquid versus Gas Operations

Application of the Human Factors Taxonomy to gas operations would likely require some initial refinement to better reflect the operational activities and risks of gas pipeline operations. Gas pipeline operations differ from liquid pipeline operations in very fundamental ways. In liquid operations, the timing of events is very critical. Because pipeline pressures can increase and exceed operating limits quickly, controlling the flow of liquid products is very time sensitive. In addition, because some operations involve transporting batches of liquid products that should not be mixed (i.e., low-sulfur diesel and most other refined petroleum fuels), the precise timing of ‘batch cuts’ is critical to operational efficiency. In contrast, the basic compressibility of gas provides more time to assess operating pressures and make appropriate adjustments. However, gas compressibility is also associated with the requirement to make the best available use of the built-in storage capacity of pipelines and to manage inflows and outflows on a long-term basis. On the safety side, the compressibility of gas results in qualitatively different leak detection procedures.

The general structure of the current taxonomy and many of the individual Performance Factors reflect operational demands that would be expected to affect gas pipeline operations. However, several of the Performance Factors in the current taxonomy were specifically defined to reflect the operational demands of liquid pipeline operations. For example, Performance Factor 1.1.2—*Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex* is worded to refer to specific liquid pipeline operations. In order to ensure that the unique operational demands of gas pipeline operations are accurately reflected in human factors risk management procedures adopted by gas operators, a careful review and revision of the Human Factors Taxonomy and related materials would be advisable.

APPLICABILITY OF OBTAINED INDUSTRY RISK ASSESSMENT RESULTS

The trial applications of the Controller Survey and Risk Likelihood Rating activity provided the opportunity to obtain an initial sample of data from the seven participating operating companies. The resulting data (see Appendix F) could be useful for the purposes of comparing results between companies as a quality control check on the results obtained from a single operator. This is a worthwhile objective that requires a fully representative set of results. The project team would like to caution against the use of the current data for such purposes. Four reasons why the current results should not be applied for such purposes are discussed below.

First, the Controller Survey has been revised since its trial application. Any comparison of trial data and future results would constitute a classic example of ‘comparing apples to oranges’. The Controller Survey is a different instrument than it was when the trial applications were conducted; so application of these results as a check on results of the final Controller Survey data – especially for the items that have been revised – would be highly suspect.

Second, the Risk Likelihood ratings were obtained from very limited samples from each of seven operators. As discussed in the Risk Likelihood section, analysis of the obtained results and consideration of the purpose of the Risk Likelihood measure suggests that Risk Likelihood ratings should be obtained from a full contingent of an operator’s pipeline operational experts to ensure a fully representative and valid sampling of risk estimates. Since the current results are based on small samples from multiple operators, their value in reviewing the ratings from a single operator have limited value.

Third, the trial applications reflect input primarily from large-scale liquid operators. As discussed above, the applicability of these findings to small- and medium-scale liquid operators, as well as gas pipeline operators, is not known.

Finally, the current trial application results are based on a limited sample of Controllers and operators. This limited sample restricts the overall generality of findings. Future applications of these procedures could serve as a useful reference when reviewing the results from an individual operator, but such a review would be better informed if it were based on a more comprehensive sample of operators.

In conclusion, the risk analysis data obtained during the trial application of risk assessment procedures were useful for the purposes of evaluating the reliability and discriminability of the corresponding rating instruments, and providing input for their refinement. Future implementation of the refined risk assessment procedures could provide a broad sample of industry data. Such future data could provide a useful comparison for individual operators in reviewing their risk assessment results, as well as generally identifying high-priority human factors topics within industry segments. However, the current set of industry risk data has several significant limitations and it does not provide an adequately valid and representative set of risk analysis results.

SUGGESTED FUTURE REFINEMENTS

The methodology and Guide developed by this project represent substantial steps forward towards defining and implementing a comprehensive human factors risk assessment and management process throughout the pipeline industry. However, the final outputs of this project do not represent a set of ‘turn key’ products that can be implemented by all industry segments. Indeed, there are a number of obvious refinements that could be initiated to support the implementation of this methodology, as discussed below.

Adapt Methodology beyond Large-scale Liquid Pipeline Operations

The applicability of the current methodology beyond large-scale liquid pipeline operators is discussed earlier in this section. As noted, the Guide might be fully applicable to small- and medium-scale liquid operators in its current form; but the necessary information to support this determination is not available at this time. A coordinated effort that implemented the current Guide with a range of liquid operators and collected feedback from those operators would provide the necessary information to determine if the Guide should be implemented by all liquid operators in its current form, or refined to address operational factors that are specific to the scale of operations.

The preceding discussion also identifies probable limitations in the applicability of the current Human Factors Taxonomy and corresponding procedures to gas pipeline operators. As noted in that discussion, much of the framework and specifics of the current Guide should be applicable to the gas industry. However, it would be most prudent if a front-end analysis were conducted in order to tailor the Human Factors Taxonomy and associated materials to the operational demands of the gas pipeline industry prior to taking steps toward implementation.

There are several excellent references that provide general guidance to process control industries regarding the assessment and management of human factors risks in the control room environment. However, the current procedures may represent a framework that could have beneficial applications outside of pipeline monitoring and control operations. As discussed above, the current guide requires substantial refinements prior to full implementation within the intended scope of pipeline monitoring and control operations in the control room. However, if such implementation efforts prove to be successful, consideration of additional applications within other segments of the petroleum industry and process control industries may be warranted.

Implement the Procedures in Computer-Based Tools

The current version of the *Liquid Pipeline Operator's Control Room Human Factors Risk Assessment and Management Guide* is a paper-based document that is over 400 pages in length. It contains two rating instruments, several calculation procedures, numerous worksheets and summary forms, and two major sets of guidance that are intended to support worksheet preparation. Each of the separate guide elements is intended to support a progressive, integrated process of information gathering, analysis, and documentation. Much of the information, data, and results obtained from individual steps are intended to be transferred to subsequent steps. With a paper-based set of procedures, this data transfer will either be accomplished manually; or individual operators will develop their own computer-based tools to support selected steps.

The coordinated development of computer-based tools to support the application of the current guide would represent a substantial savings to industry, both in total development costs and required implementation resources. It would also have the added benefit of helping to standardize the actual process that is implemented by individual operators, since tools and procedures would not be unnecessarily modified. The potential scope of computer-based tool development is substantial. At the more modest end of the development spectrum, stand-alone spreadsheets and electronic forms could be developed to help operators conduct and document individual steps in the process. At a moderate level of development, the separate spreadsheets and forms could be integrated under a single software program to facilitate data transfer and reduce resource requirements. At the more ambitious level of development, the separate rating instruments, instructions, and guidance in the Guide could be linked to the appropriate worksheets and spreadsheets to provide a fully integrated computer-based Guide.

Develop Human Factors Incident Investigation Procedures

Human Factors incident investigation and reporting programs have been successfully implemented by U.S. regulatory agencies in the nuclear power and aviation industries for over a decade. In both of these cases, a standard human factors taxonomy tailored to the operational demands of the industry is coupled with a well-defined incident investigation procedure to provide a reliable and valid source of human factors data that can be used to identify common and emerging issues within the industry. The current Human Factors Taxonomy and operational review procedures provides an excellent technical basis for developing a liquid pipeline operator incident investigation and reporting procedure. Using the taxonomy and associated operation review topics as a starting point, a series of investigation questions could be developed to result in a detailed set of conclusions corresponding to the role of human factors in all incidents that are investigated. Such results would directly complement the risk assessment activities, as well as provide a valuable source of data that could be used in databases across operators, as discussed below.

Evaluate the Efficacy of Mitigations

The guide currently identifies 86 individual mitigations that each are applicable to one or more of the 138 Performance Factors identified in the Human Factors Taxonomy. The level of evidence supporting each of these mitigations varies substantially. The immediately preceding discussion highlights the potential, converging value of both the risk assessment process and standardized incident investigation in supporting the identification high-priority human factors topics within the industry. These same two sources of information could also provide the basis for evaluating the efficacy of mitigation efforts. It is important to recognize that 'organizational outcome research' of the type involving mitigation evaluation is confounded by many factors, including differences in mitigation implementation, scope, and timing; as well as many other uncontrolled organizational factors. However, systematic collection of incident data and the repeated application of the risk assessment procedures by individual operators could support both an individual operator's evaluation of mitigation efficacy and a more robust and reliable industry-wide evaluation.

RECOMMENDED NEXT STEPS

The preceding discussions have outlined some of the strengths, limitations, and possible refinements to the current liquid pipeline human factors risk assessment and management methodology. In considering these issues along with the current operational and regulatory environment, the project team recommends the consideration of the following next steps in the implementation and refinement of this methodology and associated Guide.

Support Liquid Operator Implementation

A recommended **near-term** step concerns providing methodology implementation support to the liquid operator community. The current methodology represents a substantial shift in risk management practices for many liquid operators. In addition, the applicability of the Guide to small- and medium-scale operations is not well known at this time. These two considerations support the value of a coordinated, yet limited implementation effort with a sample of small-, medium-, and large-scale operators in order to both introduce this process to industry and establish a mechanism to make any necessary refinements required to better accommodate operational differences between the small-, medium-, and large-scale liquid operator segments.

Develop Computer-Based Tools

A second recommended **near-term** step involves the development of an initial set of computer-based tools. It is recommended that development begin modestly by first developing a set of stand-alone spreadsheets and electronic forms that would help operators conduct and document individual steps in the process. These tools could be developed with relatively modest resources, taking advantage of analytical tools developed by Battelle during the current project. After development of these initial tools, it would be easier to determine if the future scope of industry methodology implementation would warrant more extensive computer-based tool development.

Develop Human Factors Incident Investigation and Reporting Procedures

A third recommended **near-term** step concerns the development of a pipeline industry human factors incident investigation and reporting procedures. As noted above, these procedures could be developed using the current Human Factors Taxonomy and operational review procedures as the starting point in developing standardized investigation and reporting procedures for liquid pipeline operators. Future refinement of the taxonomy to gas operations would provide the technical basis for efficient development of analogous procedures for that industry segment. The resulting investigation and reporting procedures would complement an operator's risk assessment procedures based on the current methodology; as well as provide useful input to broader industry databases discussed below.

Adapt the Guide to Gas Operations

A recommended **longer-term** step concerns the adaptation of the current methodology to gas operations. Much of the current methodology and guide is directly applicable to gas operations. However, because the underlying Human Factors Taxonomy directly determines the detailed content of all elements of the Guide, the entire methodology and Guide should be adapted to better meet the needs of gas operators. This process would entail the following basic steps: replication of Controller interviews with a representative sample of gas operators; refinement of the Human Factors Taxonomy to directly reflect the demands of gas operations; and the incorporation and trial application of the refined Human Factors Taxonomy in all steps of the risk assessment and management process to identify any procedural steps that require adaptation. Such an activity could leverage the findings and lessons learned from the present project to produce a final Guide ready for implementation within the gas community in a relatively short period of time.

Develop and Maintain an Industry Risk Assessment Database

A second **longer-term** step concerns the development of an industry-wide risk assessment database consisting of the risk assessment data from individual operators. An industry risk assessment database would provide two major benefits. First, it would provide a stable source of industry-wide risk assessment results with which individual operators could compare their risk assessment findings. Second, it could provide a stable and reliable basis for reviewing common human factors concerns across industry; which in turn could be used to define and support cost-effective industry human factors risk management initiatives. The near-term steps outlined above could lay the groundwork for this activity by providing computer-based tools that could serve as the source for a standardized database; and supporting the broad level of implementation that would provide a representative sample of operators who could provide their risk assessment data. The risk assessment database would be comprised of confidential input from individual companies, which could be compiled and de-identified by a third-party contractor in the same manner as the trial results during the current project.

Develop and Maintain an Industry Incident Database

A third **longer-term** step concerns the development of an industry-wide incident database consisting of the incident investigation reports from individual operators. An industry incident database would complement the risk assessment database outlined above and provide a second valid source of data that could be used in reviewing common human factors concerns across the pipeline operating industry. As noted above, the development of incident investigation and reporting procedures could lay the groundwork for this activity by defining standardized outputs that could serve as the source for this database.

Develop and Maintain a Mitigation Evaluation Database

A fourth recommended **longer-term** step concerns the development of a pipeline industry mitigation evaluation database. Such a database would best be populated by numerous industry sources, including periodic operator risk assessment results, operator mitigation plans, surveys of operator organizational factors, and standardized operator incident human factors reports. Over time, such a database could provide an empirical basis that could support both the pipeline industry and broader process control industry in evaluating the relative value of alternative mitigations in addressing human factors issues. This is a highly ambitious effort, but one that is not beyond reason in an environment where industry and government organizations are collaborating to cost-effectively manage human factors risks.

Inter-relationships among the Recommended Next Steps

Figure 14 depicts some of the functional inter-relationships and logical precedences among the recommended next steps. The support of liquid pipeline operator implementation and development of basic computer-based risk management tools are seen as complementary tasks that should be implemented concurrently. The findings from initial liquid pipeline operator implementation would support the subsequent refinement of the Guide and would also facilitate subsequent adaptation of the Guide for gas pipeline operator implementation. The development of human factors incident investigation and reporting procedures would support future incident database development and maintenance. Initial development of basic computer-based risk management tools would support any subsequent computer-based tool development. In addition, computer-based tools would provide the standardization of procedures and data required for the development of a risk assessment and mitigation evaluation databases, which would provide converging data to support the broader identification of high-priority human factors issues.

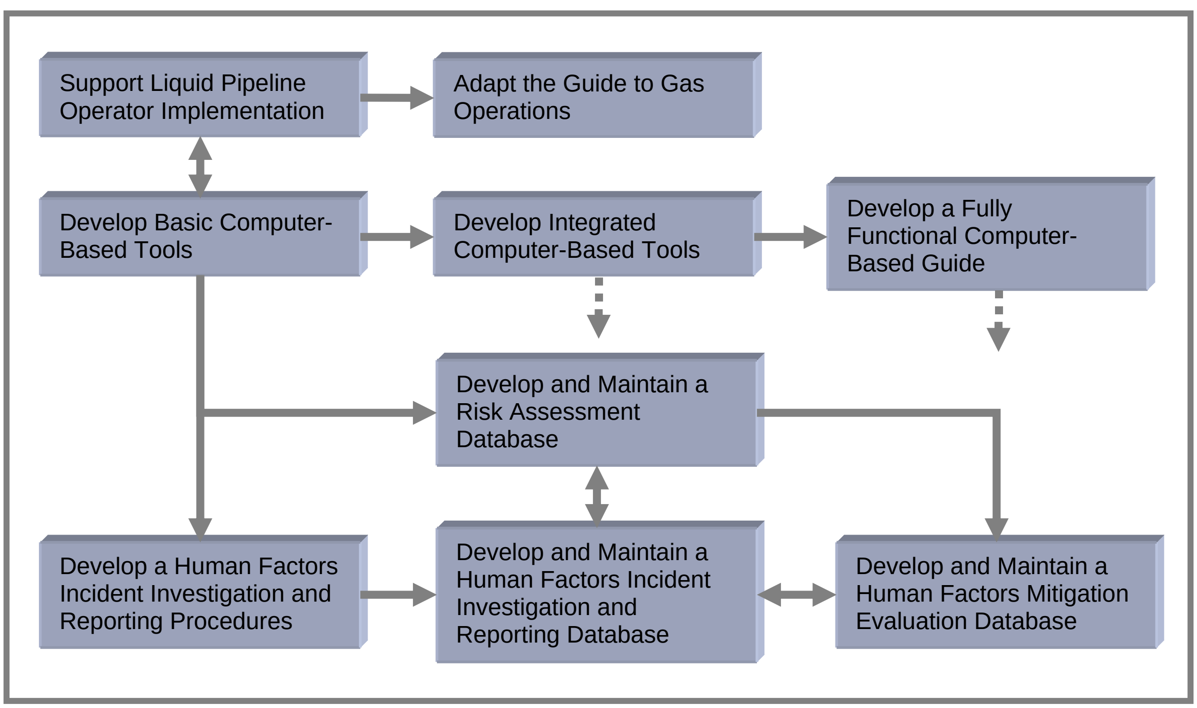


Figure 14. Inter-relationships Among Recommended Next Steps

TECHNICAL REPORT REFERENCES

Ahlstrom, V. & Longo, K. (2003). *Human Factors Design Standard (HFDS) for acquisition of commercial off-the-shelf subsystems, non-developmental items, and developmental systems*. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

American Petroleum Institute (API). (2008). *Recommended practice for pipeline SCADA displays* (API RP 1165). Washington DC: Author.

Attwood, D., Deeb, J., & Danz-Reece, M. (2004). *Ergonomic solutions for the process industries*. New York, NY: Elsevier Inc.

Center for Chemical Process Safety of the American Institute of Chemical Engineers. (1994). *Guidelines for preventing human error in process safety*. New York, NY: Author.

Crowl, D. (Ed.). (2007). *Human factors methods for improving performance in the process industries*. Hoboken, NJ: John Wiley & Sons.

Dekker, S. (2002). *The field guide to human error investigations*. Aldershot, UK: Ashgate Publishing Company.

Department of Defense. (1999). *Department of Defense design criteria standard: Human engineering* (MIL-STD-1472F). Washington, DC: Author.

Hastie, R. & Dawes, R. (2001). *Rational choice in an uncertain world: The psychology of judgment and decision making*. Sage Publishing.

Mannan, S. (Ed.). (2005). *Lee's loss prevention in the process industries*. New York, NY: Elsevier Inc.

O'Hara, J., Brown, W.., Persensky, J., Lewis, P., & Bongarra, J. (2004). *Human factors engineering program review model* (NUREG-0711, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

O'Hara, J., Higgins, J., Lewis, P., & Persensky, J., (2002). *Human-system interface design review guidelines* (NUREG-0700, Rev. 2). Washington, DC: U.S. Nuclear Regulatory Commission.

National Transportation Safety Board. (2005). *Safety study: Supervisory control and data acquisition (SCADA) in liquid pipelines*. Washington, DC: Author.

Paradies, M., Unger, S., Haas, P., & Terranova, M. (1993). *Development of the NRC's Human Performance Investigation Process (HPIP)* (NUREG/CR-5455, Vols. 1, 2, & 3). Washington, DC: U.S. Nuclear Regulatory Commission.

Rasmussen, J. (1982). Human errors: A taxonomy for describing human malfunction in industrial installations. *Journal of Occupational Accidents, 4*, 311-335.

Rasmussen, J. (1983). Skills, rules, and knowledge: Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics, SMC-13*(3): 257-266.

Reason, J. (1990). *Human error*. Cambridge, UK: Cambridge University Press.

Reason, J. (1995). A systems approach to organizational error. *Ergonomics, 38 (8)*. 1708-1721.

Shappell, S. & Wiegmann, D. (2000). *The Human Factors Analysis and Classification System–HFACS* (Report No. DOT/FAA/AM-00/7). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.

Shattuck, L. G., & Woods, D. D. (1994). The critical incident technique: 40 years later. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, 1080-1084.

Sheridan, T. (2002). *Human and automation: System design and research issues*. Santa Monica, CA: Human Factors and Ergonomics Society.

Strauch, B. (2002). *Investigating human error: Incidents, accidents, and complex systems*. Aldershot, UK: Ashgate Publishing Company.

Transportation Safety Board of Canada. (1998). *Integrated process for investigating human factors*. Quebec, Canada: Author.

Vicente, K. (1999). *Cognitive work analysis*. Mahwah, NJ: Lawrence Erlbaum Associates.

Vicente, K., Roth, E. & Mumaw, R. (2001): How do operators monitor a complex, dynamic work domain? The impact of control room technology. *International Journal of Human-Computer Studies*, *54* (6) pp. 831-856.

APPENDIX A: LITERATURE REVIEW FINDINGS

This appendix supplements the information provided in the Control Room Human Factors Identification section of this report, providing further details about the Human Factors Areas and issues identified through the research team's review of publicly available sources. Human Factors Areas are discussed and brief descriptions of related issues that represent potential shortcomings that could increase operational risk are described.

Task Complexity

There are fundamental limits on a Controller's abilities to process and deal with information, make sound decisions, and execute the necessary actions. While most operating situations are well within these limits, increasing task complexity increases the chance that these limits will be surpassed, which results in errors and inefficient task performance. Key factors that contribute to task complexity include:

High time pressure and workload. Controllers are more likely to make a variety of errors under these conditions and to form an impoverished mental model of current operations. One consequence of higher time pressure and workload is that Controllers may regress to more "primitive" instinctive information acquisition and response strategies, which could limit diagnosis and recovery options (Lin & Su, 1998). They may also rely more on recognition strategies (e.g., rule-based pattern matching between known problems and solutions) rather than analytical solutions – which is not necessarily detrimental as it can avoid reasoning errors (Klein & Calderwood, 1991).

Multiple interacting system elements. Accurate prediction of future system states and/or success of recovery action is difficult, if not impossible, if too many variables are involved. Individuals simply lack the mental abilities to track and project more than one or two variables at a time. Diagnosis is also poor with multiple potential causes (Patrick, Gregov, Halliday, Handley, & O'Reilly, 1999). This seems to arise from Controllers being fixated on single-cause hypotheses during diagnostic reasoning.

Indirect mapping of engineering information. Having to make mental "data transformations" (e.g., converting pump horsepower into fluid pressure) is mentally effortful and is more likely to lead to error-prone results (Cellier, Eyrolle, & Marine, 1997). Similarly, data may also have been filtered or transformed, which can lead to opaqueness for Controllers (Brehmer, 1990).

Displays and Controls

Displays and controls are the primary tools for obtaining information about operational parameters and executing control actions over the system. Inadequately designed and implemented displays and controls can increase task complexity and introduce errors. Some of the main issues include:

Controllers not acquiring necessary information (inadequate information presentation). This occurs if critical information is not part of the immediate display and is missed or must be sought. This typically arises following insufficient planning or research into the design of a display screen. It is important to base the design around an analysis of the task and information requirements with which a particular display will be associated. Problems can also arise if critical information is displayed in a manner that can be missed, misread, or takes too long to find under normal or emergency conditions (Den Buurman, 1991). This situation arises from display screen layouts that fail to follow good human-computer design principles.

Information access interfering with normal or emergency operations. If excessive display navigation between display screens is required to access necessary information, it can interfere with operating activities (Ranson, 1992).

Display not clearly conveying dynamic aspects of operations. Pipeline product delivery involves data about operational parameters that are typically distributed across large geographic distances, and that change over time in important ways as the delivery progresses. Controllers need to understand the significance of this information across time and space, otherwise future-system-state prediction and problem diagnosis, etc., could be negatively affected (Jamieson, 2002). This "big-picture" level of understanding can potentially be facilitated by appropriate display formats or, conversely, hindered by inappropriate display formats.

Inadequate Communication

During many normal and off-normal situations, Controllers must communicate the present state of the system to other individuals who may have to take over some or all of the operational decision-making. Thus, safe, reliable, and efficient control of operations depend on accurate and timely communication of all necessary operations information among individuals. Some communication problems that can arise include:

Inadequate shift hand-off briefing. Effective shift hand-off requires the communication of clear specification and understanding of future production goals, an accurate mental representation of current operations, and an accurate internal model of process dynamics (Lardner, 2000). Failure to properly brief next-shift Controllers on operational abnormalities or other notable events or trends can hinder problem diagnosis and recovery and generally leads to sub-optimal shift hand-offs (Grusenmeyer, 1995).

Inadequate notification of operating changes. Temporary changes in operating procedures can be missed if informally presented (e.g., as a note fixed to a display) and may be unintentionally overlooked under stressful conditions or during "automatic" Controller actions (Kletz, 2001). More specifically, once such a message has been noticed a few times, it becomes part of the background, and generally serves as an ineffective reminder.

Poor communication in emergencies. In off-normal situations, Controllers are likely to consult with or defer to more senior personnel in decision-making. The problem with this is that a failure to adequately convey all necessary situational variables can lead to inappropriate/misguided assistance or approval of actions, and sub-optimal decision-making (Dunn, Lewandowsky, & Kirsner, 2002).

Inaccurate System Information

A Controller's understanding of operations is founded on the data obtained through the information systems such as the SCADA or alarm management system. Information "noise" can lead to an inaccurate or incomplete picture of the current state of the system. This is largely an engineering problem that impacts the Controller's ability to perform his or her job. While this topic has received little attention in the human factors research literature (probably because it is largely an engineering problem), the current review of the NTSB pipeline accident reports indicated that irregularities in operations and inaccuracies in system information affected the Controller's problem detection and response on several occasions.

Although generally uncommon, inaccuracies most typically come in the form of:

Nuisance system disruptions. These are non-threatening events (external or internal) that trigger alarms, etc. (e.g., valve with improper set point), and cause the Controller to modify/compensate operating activities (e.g., ignore valve alarms). These events tend to occur with sufficient frequency that Controllers automatically attribute certain idiosyncratic system symptoms to these causes. Consequently, it can cause Controllers to incorrectly view evidence of real system failings as a result of these nuisance disruptions. These false hypotheses cannot only delay actual diagnosis of the problem but also lead Controllers to take actions that are inappropriate for the situation.

Incorrect system information. Faulty data readings, mislabeled or incorrectly depicted schematic information, etc., can lead to false assumptions in normal operations, failure diagnosis, and recovery planning. Unless they have evidence to the contrary, Controllers will undoubtedly assume that the information that they are provided is accurate, and consequently base their operations, diagnosis, and recovery actions on the available information.

Inadequate Written Procedures

Given the large number of potential events that Controllers may encounter, in addition to how infrequently many occur, it is impractical to rely on Controller memory and training to provide guidance on how to respond to off-normal situations. Thus, Controllers must be able to rely on procedures to provide clear and effective solutions to both routine and critical situations. Potential issues regarding procedure use and reliability include:

Unclear procedure information. Procedures are less likely to be followed if they cannot clearly be understood, or if the Controller has low confidence that they will work (e.g., if out-of-date). It can also be problematic if the procedure as written (usually by someone without hands-on experience) does not reflect how the task is actually accomplished in real-world settings (Center for Chemical Process Safety of the American Institute of Chemical Engineers, 1994).

Procedure information access difficulties/barriers. Controllers must be able to locate and access procedures (including finding the entry and exit steps) in a timely manner; otherwise they may go unused.

Alarm presentation/management

Alarms are a central method for informing Controllers about the changing status of operations; however, inadequate implementation of the alarm system can significantly reduce its usefulness and even hinder performance. Some of the primary issues involve:

Controllers not acquiring necessary information. Alarm presentation rate may approach 50-300 alarms per minute during off-normal plant operations (Stanton, Harrison, Taylor-Burge, & Porter, 2000). This brings up the problem of identifying and responding to alarms that deserve attention. As a result, critical alarms can be missed because of presentation format (e.g., buried in flood, or several pages back) and many alarms are simply ignored. In particular, one study found that Controllers only acted on approximately 7 percent of alarms presented (Kragt, & Bonten, 1983).

Alarm handling procedures interfering with operations. Critical alarms can be missed because of alarm handling procedures (e.g., acknowledging alarms simultaneously, acknowledging alarms without looking at them). These requirements can also interfere with diagnosis/recovery actions if Controllers continuously have to interrupt their actions to acknowledge alarms or to disable auditory warnings, etc. Also, alarm "attention-getting" properties (e.g., buzzers, flashing annunciators) can overload/distract Controller sensory channels, leading to degraded performance.

Controller Skills & Knowledge

Skills and knowledge represent a Controller's core internal "tools" that determine the Controller's capabilities for coping with the tasks required to operate the system and the ability to perform these tasks with a standard degree of competence (Fletcher, 2000). The Controller's skills and knowledge are the products of the operator qualification process and training process. The most common human factors problems include:

Insufficient knowledge of operations. Insufficient knowledge of hardware function and limits, operating procedures, etc. can lead to unsafe actions and reduced tools/options considered and used in handling problems. There are many examples in the process control industries of Controllers knowing the rote "textbook" answer to operations questions without knowing the functional significance of that information, which sometimes leads to reduced safety margins or outright system failures (Wright, Turner, & Horbury, 2003).

Inadequate Controller "mental model" of system operations. A mental model is the Controllers understanding of how the system functions, its current status, and how various operations/events/actions will affect system performance. More specifically, it is a rich and elaborate structure, reflecting the user's understanding of what the system contains, how it works, and why it works that way. It can be conceived as knowledge about the system sufficient to permit the user to mentally try out actions before choosing one to execute(Carroll, & Olson, 1987). A mental model is formed through training and operational experience. Inadequate mental models diminish a Controller's ability to anticipate future system states and problems, diagnose problems, and plan successful recovery actions (Roth, Woods, & Gallagher, 1986).

Insufficient Controller experience/expertise. Inexperienced Controllers have an impoverished understanding of the relationships among system elements, risk perception, and the functioning of system processes (Rogalski & Samurcay, 1992). This can lead to inefficient system operation, limitations in problem solving and anticipation of future events. In contrast, experts develop refined mental models of how the system operates, which allows them to make predictions about the results and evolution of various actions and in planning the future course of action to deal with these events (Cara, & Lagrange, 1999). One advantage of these more elaborate mental models is that they allow experts to incorporate more operational information into their strategies and actions to fine-tune the overall process operations (Prietula, Feltovich, & Marchak, 2000). In addition to a good internal model of process dynamics, experts also employ a set of explicit control strategies that allow them to manipulate process dynamics to their own advantage.

Coping with Stress

Work stress is an unavoidable characteristic of the Controller's job during off-normal and emergency situations. Stressful situations occur whenever there is a substantial imbalance, either real or perceived, between the demands of a situation and an individual's ability to handle those demands. Abnormal and emergency conditions, plant outages, and start-up activities can all be periods of significant operator stress. Stress can degrade performance at just the time when the Controller has the least margin of error available for avoiding minor or major consequences. Importantly, different people will respond differently to the same stressors. Factors that affect performance of individuals under stress include:

Experience coping with stress. Persons that have little previous experience with stressful events do not perform as well under stress as those that do have experience (Gertman, Haney, Jenkins, & Blankman, 1985). Performance problems can include impairments of memory, attention, communication patterns, and a tendency to perform activities as if under time pressure (Desaulniers, 1997).

Personality factors. Certain personality factors predispose some people to more efficient coping and problem solving under stress. Some of the factors that have been investigated include *motivation* (the factors that drive a person's work decision and choices), *risk-taking*, *locus-of-control* (whether someone attributes the causes of an event to personal/internal or to external factors), *emotional control* (ability to inhibit emotional responses during a crisis), and personality type (e.g., Type A – driven vs. Type B – relaxed).

Controller Alertness (Fatigue)

Fatigue arising from extended work durations and lack of sleep can negatively impact performance. There are several aspects of pipeline operations that promote fatigue among Controllers, including the use of 12-hr shifts, and nightshifts. The most common issues involve:

Extended shift durations. Time-on-task in general and longer shift durations (e.g., 12-hr instead of 8-hr shifts) reduce Controller performance efficiency and increase performance errors (Rosa & Bonnet, 1993). Other problems include reduced alertness, mild to moderate sleep loss, and specific operational deficiencies such as reduced monitoring of SCADA data (Andorre & Queinnec, 1998). These problems are not simply temporary issues related to the transition to a longer work shift, but are chronic problems and persist even several years following the work shift transition (Rosa, 1991).

Sleep Disruption. Lost sleep arising from a shift schedule that is out of phase with natural wake/sleep cycles (circadian cycle) reduces Controller cognitive and performance efficiency and increases performance errors (Pilcher & Huffcutt, 1997). This most often happens when a worker is transitioning to a work shift schedule that is out of sync with his or her regular sleep-wake patterns. This problem also affects Controllers that can be awake for extended periods with little or no sleep (e.g., on-call Relief Controllers).

Discordant Shift Schedule and Circadian Cycle. Even if Controllers receive sufficient sleep, performance errors for some activities can increase if they are working during the 'sleep phase' of their wake/sleep cycles, often because general alertness is reduced. This partially explains why operation errors, especially critical ones, are more common at night (Dahlgren, 1988).

Automation

Automation in control systems is defined as "… a device or system that accomplishes (partially or fully) a function that was previously carried out (partially or fully) by a human operator" (US National Research Council, Panel on Human Factors). In the pipeline industry this most often takes the form of automated data collection and aggregation in the SCADA, and in automated warnings and event logging of the alarm management system. Although automation in process control has led to significant gains in productivity and safety, it has also introduced a new set of human factors problems. These include:

Poor situation awareness. Automating aspects of operations can hide the current and historical status of certain variables, and can impoverish the Controller's mental model. Operators working with automated systems may be ineffective in overseeing these systems and intervening effectively as highly automated systems will place them in the role of passive system monitor – a role which has been linked to low levels of situation awareness (Endsley, Onal, & Kaber, 1997). This can lead to slower problem detection and cause Controllers to require extra time to reorient themselves to relevant system parameters in order to proceed with problem diagnosis and assumption of manual performances (Endsley & Kiris, 1995).

Over reliance on automation (complacency). The sampling and critical evaluation of information from an automated system decreases for highly reliable systems. Essentially, if a reading is always correct, it will take a significant amount of contrary evidence for an individual to question its validity, which can lead Controllers to accept incorrect data readings as true (Moray, 2003). A related problem is that important information that basically never changes (e.g., a pump status display), because it is associated with highly reliable equipment, can be easily overlooked once related Controller actions become "automatic," even if this information is presented in full view.

Under-reliance on automation. If trust/confidence in automation is low, or if automation is too cumbersome to use, Controllers may abandon or underutilize automation (Lee, & Moray, 1992). Specifically, faults in automation can abruptly reduce trust, but subsequent fault-free performance can restore it (Lewandowsky, Mundy, & Tan, 2000). It is also important that faults related to a specific function in one subsystem can also reduce trust in other functions from the same subsystem – however, mistrust does not seem to spread to other independent sub-systems (Muir, & Moray, 1996).

Literature Review References

Andorre, V., & Queinnec, Y. (1998). Changes in supervisory activity of a continuous process during night and day shifts. *International Journal of Industrial Ergonomics, 21*, 179-186.

Brehmer, B. (1990). Towards a taxonomy of microworlds. In J. Rasmussen, B. Brehmer, M. de Montmollin, & J. Leplat (Eds.). *Taxonomy for Analysis of Work Domains. Proceedings of the First MOHAWC Workshop* (pp. 1-21). Roskilde, Denmark: Risö National Laboratory.

Cara, F., & Lagrange, V. (1999). Emerging expertise in process control. *Ergonomics, 42*, 1418-1430.

Carroll, J. M., & Olson, J. R. (1987). *Mental models in human-computer interaction. Research issues about what the user of software needs to know*. Washington DC: National Academy Press.

Cellier, J. M., Eyrolle, H., & Marine, C. (1997) Expertise in dynamic environments. *Ergonomics, 40*(1), 28-50.

Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE). (1994). *Guidelines for preventing human error in process safety*. New York: Author.

Dahlgren, K. (1988, June). Shift work, work scheduling, and their impact upon operators in nuclear power plants. In E. W. Hagen (Ed.), *Conference Record for 1988 IEEE Fourth Conference on Human Factors and Power Plants*, Monterey, California (pp. 517-521). New York: Institute of Electrical and Electronics Engineers.

Den Buurman, R. (1991). Ergonomic design of monitoring displays for control rooms. In V. Popovic & M. Walker (Eds.), *Ergonomics and Human Environments, Proceedings of the 27th Annual Conference of the Ergonomics Society of Australia* (pp 75-80). Downer, ACT: Ergonomics Society of Australia.

Desaulniers, D. R. (1997). Stress in the control room: Effects and solutions. In D. I. Gertman, D. L. Schurman, & H. S. Blackman (Eds.). *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, 14-1.

Dunn, J. C, Lewandowsky, S., & Kirsner, K. (2002). Dynamics of communication in emergency management. *Applied Cognitive Psychology, 16*(6), 719-737.

Endsley, M. R., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors, 37*(2), 381-394.

Endsley, M. R., Onal, E., & Kaber, D. B. (1997, June). The impact of intermediate levels of automation on situation awareness and performance in dynamic control systems. *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants*, Orlando, Florida. New York: Institute of Electrical and Electronic Engineers.

Fletcher, S. (2000) *Competence-based assessment techniques*. London: Kogan Page.

Gertman, D. I., Haney, L. N., Jenkins, J. P., & Blankman, H. S. (1985). Operator decision making under stress. In G. Johannsen, G. Mancini, & Y L. Martensson (Eds.). *Analysis Design and Evaluation of Man-Machine Systems, Proceedings of the 2nd IFAC/IFIP/IFORS Conference*, Varese, Italy

Grusenmeyer, C. (1995). Shared functional representation in cooperative tasks - the example of shift changeover. *International Journal of Human Factors in Manufacturing, 5*(2), 163-176.

Jamieson, G. A. (2002). Empirical evaluation of an industrial application of ecological interface design. *Bridging Fundamentals and New Opportunities, Proceedings of the 46th Annual Meeting of the Human Factors and Ergonomics Society*, 536-540.

Klein, G. A., & Calderwood, R. (1991). Decision models: Some lessons from the field. *IEEE Transactions on Systems, Man, and Cybernetics, 21*, 1018-1026.

Kletz, T. (2001). *An engineer's view of human error*. Rugby, Warwickshire: Institution of Chemical Engineers.

Kragt, H., & Bonten, J. (1983). Evaluation of a conventional process alarm system in a fertilizer plant. *IEEE Transactions on Systems, Man, and Cybernetic, 13*(4), 589-600.

Lardner, R. (2000). Effective shift handover. Foresight and precaution. *Proceedings of ESREL 2000, SaRS and S*, 413-422.

Lee, J. D., & Moray, N. (1992). Trust, control strategies, and allocation of function in human-machine systems. *Ergonomics, 35*, 153-184.

Lewandowsky, S., Mundy, M., & Tan, G. (2000). The dynamics of trust: Comparing humans to automation. *Journal of Experimental Psychology: Applied. 6*, 104-123.

Lin, D. Y. M., & Su, Y. L. (1998). The effect of time pressure on expert system based training for emergency management. *Behavior & Information Technology, 17*, 195-202.

Moray, N. (2003). Monitoring, complacency, skepticism, and eutactic behaviour. *Industrial Ergonomics, 31*, 175-178.

Muir, B,. & Moray, N. (1996). Trust in automation. Part II. Experimental studies of trust and human intervention in a process control simulation. *Ergonomics, 39*(3), 429-460.

Patrick, J., Gregov, A., Halliday, P., Handley, J., & O'Reilly, S. (1999). Analyzing operators' diagnostic reasoning during multiple events. *Ergonomics, 42*, 493-515.

Pilcher, J. J., & Huffcutt, A. I. (1997). Effects of sleep deprivation on performance: A Meta-analysis. *Sleep, 19*(4), 318-326.

Prietula, M. J., Feltovich, P. J., & Marchak, F. (2000). Factors influencing analysis of complex cognitive tasks: A framework and example from industrial process control. *Human Factors, 42*, 56-74.

Ranson, D. S. (1992, June). Navigating between computer displays in power plants. *Conference Record for the 1992 Fifth Conference on Human Factors and Power Plants*, Monterey, California (pp. 273-277). New York: Institute of Electrical and Electronics Engineers.

Rogalski, J, & Samurcay, R. (1992). Effects of expertise on knowledge representation in dynamic environment management. *Proceedings of the Third European Conference on Cognitive Science Approaches to Process Control* (pp. 104-114). Caerdydd : School of Psychology, University of Wales College of Cardiff.

Rosa, R. R. (1991). Performance, alertness, and sleep after 3.5 years of 12h shifts: A follow-up study. *Work and Stress, 5*(2), 107-116.

Rosa, R. R., & Bonnet, M. H. (1993). Performance and alertness on 8 h and 12 h rotating shifts at a natural gas utility. *Ergonomics, 36*, 1177-1193.

Roth, E. M., Woods, D. D., Gallagher, J. M. (1986). Analysis of expertise in a dynamic control task. a cradle for human factors. *Proceedings of the Human Factors Society 30th Annual Meeting*, 179-181.

Stanton, N. A., Harrison, D. J., Taylor-Burge, K. L., & Porter, L .J. (2000). Sorting the wheat from the chaff: A study of the detection of alarms. *Cognition, Technology & Work, 2*(3), 134-141.

Wright, M., Turner, D, & Horbury, H. (2003). *Competence assessment for the hazardous industries*. Norwich, UK: HSE Books.

APPENDIX B: CONTROLLER INTERVIEW FINDINGS

This appendix provides a summary of the results of the content analyses conducted with the two portions of the Controller interviews that dealt with (1) general conditions in the control room that affected operational safety and (2) specific factors that were judged to contribute to the occurrence of a specific safety- or efficiency-related incident under discussion with the Controller.

GENERAL CONDITIONS—NEGATIVE FACTORS

This section provides a summary of the factors identified as negatively affecting operational safety or efficiency by Controllers. For each general Human Factors Area, the percentage of Controllers interviewed who identified this area as a factor negatively affecting operational safety and/or efficiency is identified. (In all cases, the percentage of Controllers sited in this appendix refers to a weighted average, based on an equal weighting across the seven participating operators.) Then, under each area, specific factors identified through content analysis of the Controller comments are identified, along with an indication of the number of such comments identified and a single comment (in italics) that best exemplifies those comments.

Task Workload and Complexity

Task workload and complexity was identified as a factor that negatively affected operational safety and/or efficiency by an average of 63 percent of the Controllers interviewed. Four specific factors associated with the negative affects of task difficulty and complexity were identified, as summarized below.

Task demands and system complexity (19 Comments)
The line requires conversion of measurement units. Currently, this process involves several manual steps that are somewhat complicated, which has the potential for human error. This conversion could be automated.

Concurrent activities and work pace (18 Comments)
This Controller's desk is a difficult desk. There are a lot of units on the line and there is a lot of information to remember. This Controller often has three things coming up at the same time on different lines. Controllers have the ability to slow things down, but in practice, this is not always practical to do.

Unexpected problems (10 Comments)
Any abnormal situation takes time away from everything else because you have to focus your attention on the high-priority alarm. You still have other things going on, and they can surprise you because your attention is diverted towards the alarm.

Distracting secondary tasks (6 Comments)
Controllers do bi-hourly over and shorts. These can take a long time and even get in the way when something else is going on. They can take attention away from operation activities. Computerizing this task would make the Controller's job much easier.

Displays and Controls

Displays and controls were identified as a factor that negatively affected operational safety and/or efficiency by an average of 65 percent of the Controllers interviewed. Six specific factors associated with the negative affects of displays and controls were identified, as summarized below.

Scanning and searching for information (15 Comments)
Display screens are often crowded. Sometimes there is a lot of information closely packed together and it makes it difficult to pick out the needed information.

Accessing relevant information (11 Comments)
SCADA screens are not designed based on a consistent set of design standards. There is a lack of consistency across screens. The important navigation buttons are not consistently positioned. For example, a "station lock" is an important control, but it is sometimes found in different locations on different screens.

Interpreting displayed information (11 Comments)
The use of yellow (for run/open) and green in the displays is less intuitive because both can mean normal state operation.

Executing control actions (8 Comments)
There is an inability to perform control actions from the overview screens. This can result in Controllers making a large number of navigation-related actions. It also makes it difficult to keep track of what is going on in the system as a whole because Controllers spend a lot of time in station screens that do not provide overview information.

Viewing and accessing equipment (8 Comments)
The way the displays are set up, monitors are angled which leads to glare and reflections on the screens.

Lack of Controller involvement in development (5 Comments)
IT personnel sometimes make too many changes to a screen without consulting Controllers about how it will impact their job.

Other (7 Comments)
Getting more information about equipment (e.g., bearing temperatures) in the field could allow the Controller to make better operating decisions.

General Communications

General Communications was identified as a factor that negatively affected operational safety and/or efficiency by an average of 70 percent of the Controllers interviewed. Three specific factors associated with the negative affects of general communications were identified, as summarized below.

Field personnel communications (21 Comments)
Platform personnel can sometimes be difficult to get in touch with. They are often busy and unavailable.

SCADA communications reliability (11 Comments)
Loss of communications with stations is a big problem. It makes the job more difficult, because you have to contact someone you don't normally deal with. These communications also have to be documented.

Scheduler communications (7 Comments)
The communication flow for scheduling changes is problematic. There is no common protocol. Changes can come from different people, and not everyone gets the same information, even Controllers. This Controller has had experiences in the past where s/he was not informed about a change until after the deliver time was supposed to begin.

Other (4 Comments)
If something is going on (e.g., operational changes), the team leader is the first contact, and the Controller gets the information indirectly. This Controller prefers to be the point of contact because s/he is responsible for the line. Controller don't get as complete a picture of the situation. There is also the risk that the Controller might not get the information in a timely manner.

Shift Change-over Communications

Communications during the shift change-over was identified as a factor that negatively affected operational safety and/or efficiency by an average of 43 percent of the Controllers interviewed. Three specific factors associated with the negative affects of shift change-over communications were identified, as summarized below.

Shift change-over procedures (13 Comments)
Line situation reports present important and pertinent information that consistently requires attention during change-over. However, after 24 hours, issues are printed and dropped from the immediate list. This means that Controllers coming on later can still miss important line information if it gets too far down the stack.

Shift change-over execution (9 Comments)
Some Controllers are not as disciplined in following shift change-over procedures as others. This can lead to changeovers that do not go as smoothly as they could and in Controllers not having as clear an understanding of current operations as they should.

Time available for shift changes (9 Comments)
Some Controllers come in right before the start of the shift, which sometimes leaves insufficient time for a thorough change-over debriefing. The previous Controller is usually in a hurry to leave, and some information can get left out or not covered in [sufficient] detail.

Other (3 Comments)
After changeover, a Controller inherits previous control set points from the previous shift. Controllers need to be careful that there are no surprises.

System Information Access and Accuracy

System information access and accuracy was identified as a factor that negatively affected operational safety and/or efficiency by an average of 51 percent of the Controllers interviewed. Three specific factors associated with the negative affects of system information access and accuracy were identified, as summarized below.

Inaccurate dynamic information (25 Comments)
Meters stop working or speed up. There is no direct indicator that the status is wrong.

Inaccurate static information (10 Comments)
The Controller often finds that the SCADA screens have inaccuracies in schematics. This includes several units that are present on the line but are not represented in the SCADA.

Inaccurate status indicators (7 Comments)
Some pressure and rate alarms are set at the wrong spot. Some of these were even set above MOP (corrections have been made).

Other (5 Comments)
With new lines coming in, there may be some information that Controllers expect to have access to but which may not yet be available.

Written Procedures

Written procedures was identified as a factor that negatively affected operational safety and/or efficiency by an average of 36 percent of the Controllers interviewed. Three specific factors associated with the negative affects of written procedures were identified, as summarized below.

Procedure updating, control and notification (13 Comments)
Changes to console-specific procedures are for too often passed on verbally or by e-mail. E-mail is not reliable if it was sent out before the Controller started working at the company. Relying on informal communications can make it likely that Controllers do not get the information they need.

Procedure access (8 Comments)
Most procedures are in another room in a cabinet, which makes them inconvenient to access.

Procedure interpretation (6 Comments)
Written procedures are a little abstract. They are not specific enough to provide information about all the steps that must be taken for particular delivery activities.

Alarm Presentation and Management

Alarm presentation and management was identified as a factor that negatively affected operational safety and/or efficiency by an average of 71 percent of the Controllers interviewed. Four specific factors associated with the negative affects of alarm presentation and management were identified, as summarized below.

Nuisance alarms (7 Comments)
There are a lot of repetitive or unnecessary alarms. The same problem will trigger multiple alarms that are not all necessary and it clutters up the alarm display and makes it more complicated to acknowledge them.

Alarm meaning interpretation (7 Comments)
Some of the descriptions of the alarms have unfamiliar/ unintuitive abbreviations. The abbreviations are determined by non-Controllers, sometimes without consultation with Controllers. The terminology used may not match that of the Controllers.

Alarm acknowledgement (6 Comments)
There are a lot of alarms. It helps keep you on your toes, but having to clear alarms can get in the way of performing other operational activities.

Alarm priority determination (4 Comments)
The color coding of the alarms requires attention to avoid confusing red with orange.

Other (7 Comments)
This Controller would like to have a dedicated screen for unacknowledged alarms. Currently s/he needs to use up a screen (that could be used for other purposes) to show this display.

Controller Skills and Knowledge (Training and Mentoring)

Controller skills and knowledge (discussed in terms of Controller training and mentoring) was identified as a factor that negatively affected operational safety and/or efficiency by an average of 37 percent of the Controllers interviewed. Four specific factors associated with the negative affects of Controller skills and knowledge were identified, as summarized below.

Training and experience on specific system (14 Comments)
Training on a newly added line was insufficient. There were unexpected operational difficulties that the Controllers were not prepared for. Controllers had to train with people who were losing their jobs, so the quality of training was inadequate. There was a lot of informal and idiosyncratic information that could have been useful but was not communicated.

Training on overall system functionality (3 Comments)
New Controllers might not be getting as much training as they should get. The assumption is that the shift supervisor is available to help out, but supervisors may be busy doing other things and not as available to oversee new Controllers.

Value of field experience or exposure (3 Comments)
Current training does not provide enough time in the field. This leaves Controllers with insufficient understanding of what is going on and how the system really operates. Controllers don't get a true picture of the impact of system malfunctions on the pipeline components. Field experience provides a better understanding of what is really happening in the line and allows Controllers to make better decisions at the console.

Training in fundamentals (hydraulics) (1 Comment)
Additional hydraulics training would be useful for helping in dealing with unusual batch sequences (e.g., heavy product sandwiched in between lighter more compressible product. These sequences can lead to different pressure situations that the Controller has less experience with.

Coping with Stress

Coping with stress was identified as a factor that negatively affected operational safety and/or efficiency by an average of 55 percent of the Controllers interviewed. Six specific factors associated with the negative affects of coping with stress were identified, as summarized below.

Managing workload and pace (9 Comments)
Most times when there is an off-normal situation, the phones start ringing off the hook. These calls are disruptive, but on the other hand, Controllers don't want to just ignore them

because one of the calls may provide important information about why the off-normal situation is occurring.

Off-normal situations (9 Comments)
If critical situations are occurring, it can be highly stressful if the other lines also have to be operated. This Controller does not have a cross-trained Controller at the other desk that can take over some line operations.

Coordination with others (8 Comments)
Stress does not come from the line because operation is second nature. However, having to accommodate demands from others, including managers and field personnel, at these times is what causes stress. They aren't usually aware of what Controllers are dealing with at the time and cause unnecessary disruptions.

Burden of secondary tasks during emergencies (3 Comments)
Controllers are expected to collect data (screen captures) before shutting down the line during an incident. This is disruptive. Data collection requires navigating away from the current screen. Typically, the Controller is too busy monitoring important information and thinking about how to deal with the situation to want to leave the current screen. An automatic "capture abnormal data" button would make this easier.

Meeting operational goals (3 Comments)
Pay bonuses, compensation, and evaluation are related to avoiding red-letter goal violations (team members will also lose half of their bonus). Some red-letter goal violations seem disproportionately serious. The threat of committing a violation can make Controllers tentative; but Controllers must be confident, fast, and responsive because you can't take back an interface if it goes by.

Distractions in control room (1 Comment)
Distractions [can be a problem], including phone calls and traffic, and others talking nearby while this Controller is trying to focus in the control room.

Controller Alertness (Fatigue)

Controller alertness (fatigue) was identified as a factor that negatively affected operational safety and/or efficiency by an average of 65 percent of the Controllers interviewed. Five specific factors associated with the negative affects of Controller alertness were identified, as summarized below.

Discordant shift and circadian cycles (18 Comments)
The 0200 to 0400 time frame is the most difficult to stay awake. This Controller notices making more little mistakes (e.g., keystroke entries) during this time but catches these. This almost never happens during the day shift.

Sleep between shifts/ sleep quality (7 Comments)
This Controller has low alertness periods during the day shift. This Controller actually gets more and better sleep on night shift because there are fewer interruptions at home.

Activity level/ stimulation during shifts (3 Comments)
Fatigue occurs more often on the night shift because activity levels are lower.

Chronic fatigue (3 Comments)
This Controller feels the effects of drowsiness daily, but has work-arounds for dealing with these.

Extended shift durations (3 Comments)
This Controller does get tired during night shifts or towards the end of the shift. Alertness is not 100 percent but it does not noticeably affect performance. The drive home can be a little difficult, though.

Automation

Automation was identified as a factor that negatively affected operational safety and/or efficiency by an average of 18 percent of the Controllers interviewed. Two specific factors associated with the negative affects of automation were identified, as summarized below.

System status tracking (4 Comments)
Flow controllers are cascaded to pressure controllers. This Controller knows that the pressure controllers are there, but they are not shown on the SCADA. This Controller can figure out what the pressure controllers are doing, but can not directly observe what they are doing, which makes it somewhat more difficult to figure out what is going on in that part of the line.

Automated functions (3 Comments)
Automatic surge reduction is useful if the Controller is away from the console. [However], it has caused some problems when the Controller has already begun taking action to address the situation and the surge reduction automatically activates. This leads to unnecessary shut downs when the Controller actually has the situation under control.

Other (6 Comments)
The system may take 30-45 minutes to respond using set points. Controllers have to monitor that everything is happening as expected. This time interval can vary significantly for different products.

Control Room Staffing

Control room staffing was identified as a factor that negatively affected operational safety and/or efficiency by an average of 17 percent of the Controllers interviewed. Six specific factors associated with the negative affects of control room staffing were identified, as summarized below.

Lack of breaks during shift (24 Comments)
There are no breaks for Controllers. Eating is difficult and has to be done very quickly at the desk, while continuing Controller duties. Bathroom breaks sometimes have to be accomplished in segments.

General understaffing (8 Comments)
Controllers come to work even when sick due to short staffing.

Rest between shifts (8 Comments)
This Controller strongly dislikes 12-hours shifts. Most Controllers voted for this schedule because it provides additional money but the effects of fatigue were not adequately considered. Twelve hour shifts leave Controllers continually tired, especially when commute

time is added in. It doesn't provide Controllers with enough time to unwind at home before going to sleep and regularly leads to insufficient sleep levels.

Insufficient cross-training (6 Comments)
Controllers are assigned to one console, so no one is available to cover for breaks. Breads must be taken between transactions.

Off-duty interruptions (5 Comments)
If a Controller calls in sick for a night shift other Controllers are called on the phone to come in and cover his or her shift. The relieving Controller can easily be without sleep for a 24 hour period by the end of their "extra" shift. Not coming in when called is seen as a performance issue by the company.

Lack of additional control room staff (1 Comment)
It would be very valuable to have an extra experienced Controller available on each shift to help out with limited activities (e.g., taking calls) when there is a problem with the line.

INCIDENT CONTRIBUTING FACTORS

This section provides a summary of the factors identified as contributing to a specific safety- or efficiency-related incident under discussion with a Controller. For each general Human Factors Area discussed, the percentage of Controllers interviewed who identified this area as a factor that contributed to the occurrence, severity, or effectiveness of response to the emerging incident is identified. (This is a weighted percentage, where each of the seven participating companies is weighted equally, even though the number of incidents reviewed varied between five and seven at each site.) Then, under each area, specific factors identified through content analysis of the Controller comments are identified, along with an indication of the number of such comments identified and a single comment that best exemplifies those comments. In general, the percentage of Controllers identifying factors as contributing to incidents was lower than the percentage of Controllers identifying a factor as representing a general negative effect in operational safety and/or efficiency. This was expected, since the discussions of incidents were focused on more narrowly defined situations.

Task Workload and Complexity

Task Difficulty and Complexity was identified as a factor that contributed to 39 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Concurrent activities and work pace (13 Comments)
This Controller was concurrently preparing for the shift change-over (this was a lot of work), and the pipeline was particularly busy at the time.

Task demands and system complexity (6 Comments)
The set of control actions required to execute the sequence were cumbersome and complex. The Controller made an error while managing this sequence and difficulty likely played a role.

Unexpected problems (2 Comments)
This Controller was just coming off of a high workload period and s/he perceived the upcoming (incident related) control actions as "two easier switches". This led to the Controller relaxing a little.

Displays and Controls

Displays and controls were identified as a factor that contributed to 29 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Accessing relevant information (9 Comments)
Gravitometer [status information was not available]. This switch is typically made with the gravitometer only. The optical interface is not precise enough to make the switch. There is no status information that indicates that the gravitometer has failed.

Executing control actions (5 Comments)
If the SCADA had been designed with easy access to all the units on the line on one screen, the Controller could have shut down the line a little faster. This has since been corrected as the screens have been redesigned.

Interpreting displayed information (4 Comments)
Unit operation and control actuation occurs on a station screen that does not provide overview information and the Controller was consequently unable to see units go down at another station. If there had been an overview screen, the Controller probably would have seen the unit go down, and it would have been easier to execute the necessary response.

General Communications

General communications was identified as a factor that contributed to an average of 30 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Field personnel communications (12 Comments)
There were ambiguous communications between the Controller and the field technician regarding the technician's follow-up actions in response to the unit communication loss.

Control room communications (3 Comments)
The lead Controller knew about [the schedule] change but did not pass along the information. The Controller would have been in the position to identify that the schedule changes was potentially problematic.

Scheduler communications (2 Comments)
The scheduler did not inform this Controller or the affected field technician that the schedule had been changed and that extra product had been delivered into the tank.

Shift Change-over Communications

Shift change-over communications was identified as a factor that contributed to an average of 20 percent of the incidents discussed with Controllers. Two specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Accuracy/ completeness of info exchange (6 Comments)
The previous Controller had inaccurate information. Although the error could have been identified by looking back at other data, this was beyond what Controllers would normally do during change-over. The numbers that were reviewed appeared to be fine.

Shift change-over procedures (2 Comments)
Schedule information would be outside the scope of the change-over briefing.

System Information Access and Accuracy

System information access and accuracy was identified as a factor that contributed to 40 percent of the incidents discussed with Controllers. Five specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Inaccurate dynamic information (7 Comments)
SCADA displayed a closed block valve as open.

Inaccurate static information (6 Comments)
Forecast information was inaccurate. The trend chart could have provided the necessary information, but the Controller did not put it up because the interface was not expected at that time.

Inaccurate status indicator (2 Comments)
Unit status indicated that is was communicating, but the unit was not and it was displaying stale values.

Information timeliness problems (2 Comments)
Station lost communication link.

Information interpretation (1 Comment)
Communications problems had been happening all day, and this provided an alternative explanation for the actual problem (that it was a communications problem and not a flow problem). This Controller dealt with communications as the problem before addressing the [actual] flow problem.

Written Procedures

Written procedures were identified as a factor that contributed to 33 percent of the incidents discussed with Controllers. Two specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Procedure availability/ access (6 Comments)
There are no specific procedures for double-checking the accuracy of the log.

Procedure interpretation (3 Comments)
Just what information must be passed along at shift change-over is not clearly and systematically defined.

Alarm Presentation and Management

Alarm presentation and management was identified as a factor that contributed to 30 percent of the incidents discussed with Controllers. Five specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Alarm availability (7 Comments)
Upcoming interface or volume alarms would have been helpful.

Alarm meaning interpretation (2 Comments)
The rate of change alarm was not very useful because since they typically meaningless [false alarms].

Alarm priority determination (2 Comments)
If the alarm type had been a distinctive sound (relative to other types of alarms that are not as important but have the same sound), this Controller would have better recognized the significance of the alarm while being distracted by other tasks.

Alarm reliability (2 Comments)
There were many nuisance [false] leak detection alarms on these pipelines, which made them more untrustworthy. This Controller thinks that he may have been slower to respond to the alarms because he second-guessed their validity. (The meters also went out more frequently on this line.)

Alarm timeliness (1 Comment)
If the gravitometer was further upstream, it would have given Controllers more time to respond to the interface alarms.

Controller Skills and Knowledge (Training and Mentoring)

Controller skills and knowledge (discussed with Controllers as training and mentoring) was identified as a factor that contributed 12 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Experience on specific system or procedures (2 Comments)
There was no specific training about using optical interfaces as a back-up [for gravitometers] in making switches (and no emphasis on doing so). The Controller did not consider it to be an immediate back-up option. Using the optical interface had not been emphasized to the Controller team. This Controller had not been trained to emphasize use of this device as a back-up.

Attitude and/or prioritization (1 Comment)
Training was adequate, but this Controller may not have come away with the appropriate emphasis from this training. This led to the Controller making assumptions that may not have been optimal.

Emergency operations training (1 Comment)
This Controller's inexperience led to him/her trying to "save" the line (keep it open) rather than shutting it down, which was the appropriate action.

Coping with Stress

Coping with stress was identified as a factor that contributed to 20 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Off-normal situation resulted in stress (4 Comments)
The situation was highly stressful. This Controller was concerned about injury to field personnel.

Management relations (2 Comments)
The fact that the Controller had made an error and was thinking about how management would react distracted the Controller during the response.

Managing workload and pace (2 Comments)
Possibly, because there was trouble with another line, which may have caused distractions that pulled the Controller's attention away from the task at hand.

Controller Alertness (Fatigue)

Controller alertness was identified as a factor that contributed to 10 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Activity level/ stimulation during shifts (2 Comments)
The incident occurred during a slow time and this Controller may not have paid sufficient attention to what s/he needed to do.

Extended shift durations (1 Comment)
Lack of sleep may have contributed due to shift duration and at the end of a 12-hour shift.

Sleep between shifts/ sleep quality (1 Comment)
This Controller did not have a good quality sleep the night before.

Automation

Automation was identified as a factor that contributed to 12 percent of the incidents discussed with Controllers. Three specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Error in manual procedure (4 Comments)
A line fill calculation tool that accumulated the values and required Controller acknowledgement after entering the numbers in the log would have avoided this problem.

Over reliance on automation (1 Comment)
This Controller did most of the necessary steps, but did not complete the task. There was no overt check that all the steps had been completed.

System status tracking (1 Comment)
The fail-safe mode automation [valve opened or closed] was not obvious to this Controller. Different stations fail in different ways.

Control Room Staffing

Control Room Staffing was identified as a factor that contributed to 13 percent of the incidents discussed with Controllers. Two specific factors related to this area were identified as contributing to an incident under discussion, as summarized below.

Console understaffing (1 Comment)
The console was short-staffed.

Excessive days worked (1 Comment)
This Controller experienced general fatigue related to having more days on and fewer days off than usual.

APPENDIX C: HUMAN FACTORS TAXONOMY

Following is the Liquid Pipeline Control Room Human Factors Taxonomy. The individual Human Factors Areas, Human Factors Topics, and Performance Factors are listed in a manner that makes the nesting of more detailed elements clear. The Performance Factor Identifying Number (PF ID) provided in the left-hand column corresponds directly to each Controller Survey item number that is based on one Performance Factor. In computing Human Factors Topic-level relative risk scores, scores corresponding to individual Performance Factors are first computed (see Appendix F) and then combined in accordance with the Human Factors Topic identifier in the right-hand column.

PF ID	Performance Factor	HF Topic Risk Level Calculation
Human Factors Area 1. Task Complexity and Workload		
Topic 1.1 Task Design		
1.1.1	Execution of a control action (e.g., open/close valve, start/stop pump, change setpoint) requires too many steps (e.g., more than three)	***1.1***
1.1.2	Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex	***1.1***
1.1.3	Controllers make errors in performing manual calculations that are used directly as an input to operational activities	***1.1***
1.1.4	Some equipment requires control actions that are different than similar equipment at the majority of locations	***1.1***
1.1.5	Some operations have a very small margin for error	***1.1***
Topic 1.2 Console Workload		
1.2.1	Two or more control operations (e.g., line switches) must be done at the same time	***1.2***
1.2.2	Excessive telephone activity interferes with monitoring and control operations	***1.2***
1.2.3	Shift hand-off activities interfere with operations	***1.2***
1.2.4	Unusual work conditions (trainees, tours/visitors) interfere with operations	***1.2***
1.2.5	Unusual operational conditions (smart pigging, major repairs) interfere with operations	***1.2***
1.2.6	Controllers have to make important operational decisions without sufficient time to adequately consider alternatives	***1.2***
Human Factors Area 2. Displays and Controls		
Topic 2.1 Equipment Layout and Workstation Design		
2.1.1	There are not enough display monitors to show all of the information that a Controller needs at one time during *normal* operations	***2.1***
2.1.2	There are not enough display monitors to show all of the information that a Controller needs at one time during *abnormal* situations	***2.1***
2.1.3	Monitoring and control activities are disrupted by inadequate display monitor placement (e.g., too low, too high, or positioned so that there is screen glare)	***2.1***
2.1.4	Monitoring and control activities are disrupted by inadequate monitor display quality (e.g., clarity, brightness, contrast)	***2.1***

PF ID	Performance Factor	HF Topic Risk Level Calculation
Topic 2.2 SCADA Information Access and Layout		
2.2.1	Inconsistencies in SCADA display design from screen to screen increase the difficulty of getting needed information	***2.2***
2.2.2	A cluttered, or complicated SCADA display increases the difficulty of finding needed information	***2.2***
2.2.3	The layout of information (e.g., lines, equipment, and data) on the SCADA display increases the difficulty of finding, identifying, and interpreting information	***2.2***
2.2.4	Needed information is not shown on the appropriate SCADA display	***2.2***
2.2.5	Controllers must navigate between more than two SCADA displays to view related information	***2.2***
2.2.6	Navigating between SCADA displays interferes with the flow of monitoring and control activities	***2.2***
2.2.7	The location or layout of SCADA control boxes/targets makes them difficult to use	***2.2***
Topic 2.3 SCADA Information Content, Coding, and Presentation		
2.3.1	Information about which part of the pipeline system the current SCADA display represents is not adequately provided	***2.3***
2.3.2	Some *colors* on SCADA displays make data interpretation difficult	***2.3***
2.3.3	Some *labels* on SCADA displays make data interpretation difficult	***2.3***
2.3.4	Some *symbols* on SCADA displays make data interpretation difficult	***2.3***
2.3.5	Controllers must transform values from the measurement scale presented on the SCADA display to another scale (e.g., psi to bar, gallons/min to liters/min, etc.) to complete a task	***2.3***
2.3.6	SCADA displays do not provide adequate system overview information for keeping track of system status	***2.3***
2.3.7	There is inconsistent use of units of measure (e.g., gallons, barrels, cubic meters) on SCADA displays	***2.3***
Human Factors Area 3. Communications		
Topic 3.1 Shift Hand-off Procedures		
3.1.1	Shift hand-off procedures or tools do not adequately identify, track, and record information required by the Controller coming on shift	***3.1***
3.1.2	Formal shift hand-off procedures are not adequately followed by Controllers	***3.1***
Topic 3.2 Control Center Communications		
3.2.1	The exchange of required operations information between Controllers on different consoles is not adequate	***3.2***
3.2.2	Control center staff (not including field technicians) are not available to provide assistance with an operational issue when required	***3.2***
3.2.3	The lines of communication in the control room are not clearly defined or adhered to	***3.2***
Topic 3.3 Schedule Communications		
3.3.1	Product delivery schedules are inaccurate	***3.3***
3.3.2	Changes in product delivery schedules are not communicated to Controllers at all	***3.3***
3.3.3	Changes in product delivery schedules are communicated to Controllers without sufficient lead time	***3.3***

PF ID	Performance Factor	HF Topic Risk Level Calculation
Topic 3.4 Field Personnel Communications		
3.4.1	Field technicians are not available to assist Controllers with an operational issue when required	***3.4***
3.4.2	Important field information (e.g., operational and maintenance activities) is not provided directly to Controllers in a timely manner	***3.4***
3.4.3	Field personnel communicate incorrect information about equipment (e.g., pumps and valves) status to Controllers	***3.4***
3.4.4	Field personnel do not fully communicate important ongoing operational conditions (e.g., pigging or repairs) to Controllers	***3.4***
3.4.5	Controllers have difficulty communicating with field personnel due to a lack of available communications equipment	***3.4***
Human Factors Area 4. System Information Accuracy and Access		
Topic 4.1 Operational Information Accuracy and Availability		
4.1.1	SCADA data from field instruments (meters, gauges, etc.) are inaccurate	***4.1***
4.1.2	SCADA data are stale/out-of-date, or unavailable due to a communications problem (e.g., outage, time delay)	***4.1***
4.1.3	The SCADA display does not indicate that data are out-of-date or unavailable	***4.1***
4.1.4	Changes in field system operational status (e.g., equipment identity or operational activities) are not adequately indicated in SCADA displays	***4.1***
4.1.5	Displayed pipeline schematics or operational parameters (e.g., MOPs) are inaccurate	***4.1***
4.1.6	Manually entered batch, log, and/or summary information is not accurate	***4.1***
4.1.7	Required information is not available on the SCADA display	***4.1***
Human Factors Area 5. Job Procedures		
Topic 5.1 Job Procedure Design		
5.1.1	When to use a procedure is not clearly defined	***5.1***
5.1.2	Required technical detail is not provided by a procedure	***5.1***
5.1.3	Procedures are difficult to read	***5.1***
5.1.4	Critical information is difficult to find in a procedure	***5.1***
5.1.5	Procedures do not meet the needs of both novice and experienced operators	***5.1***
5.1.6	Procedures used in responding to *abnormal* situations are difficult to follow	***5.1***
Topic 5.2 Job Procedure Availability		
5.2.1	A specific required operations procedure is not available	***5.2***
5.2.2	Finding an individual procedure among the large overall number of procedures is difficult	***5.2***
5.2.3	Procedures and job aids required to identify and recover from *abnormal* situations are not readily available	***5.2***
Topic 5.3 Job Procedure Accuracy and Completeness		
5.3.1	Procedures contain out-of-date or inaccurate information	***5.3***
5.3.2	Procedure update notifications are not adequately provided to Controllers	***5.3***

PF ID	Performance Factor	HF Topic Risk Level Calculation
5.3.3	Controllers do not understand the documented procedure	***5.3***
5.3.4	Controllers execute actions in a manner that is not consistent with established and documented procedures because the procedure is incorrect or incomplete	***5.3***
Human Factors Area 6. Alarm Presentation and Management		
Topic 6.1 Alarm Availability and Accuracy		
6.1.1	No alarm is available to notify the Controller about important current operational status information (e.g., pressure or batch interface at a specific point in the line)	***6.1***
6.1.2	Alarms do not provide the Controller with sufficient lead time to take corrective actions (i.e., because of sensor location)	***6.1***
6.1.3	Changes in operating conditions triggered by external events that are outside of Controllers' influence (e.g., equipment failure or maintenance on a feeder system) are not displayed on the SCADA	***6.1***
Topic 6.2 Alarm Display and Presentation		
6.2.1	Alarm displays become too cluttered making it difficult to identify important alarms	***6.2***
6.2.2	The alarm display shows alarms from another console and Controllers have difficulty finding the alarms for their console	***6.2***
6.2.3	High-priority alarms are ineffective in attracting a Controller's attention when performing other activities	***6.2***
6.2.4	The sound or loudness of critical alarms startles Controllers unnecessarily	***6.2***
6.2.5	The *sound* of an alarm does not clearly indicate the intended alarm priority	***6.2***
6.2.6	The *color* of an alarm does not clearly indicate the intended alarm priority	***6.2***
Topic 6.3 Alarm Interpretation		
6.3.1	The displayed alarm description is difficult to interpret	***6.3***
6.3.2	There are multiple causes for some alarms, but insufficient information is provided to identify the actual cause	***6.3***
6.3.3	Alarm summary information does not provide adequate information about conditions at the time that the alarm was triggered	***6.3***
6.3.4	Alarms are not displayed in a consistent format, making their interpretation difficult	***6.3***
6.3.5	It is difficult to determine the intended priority of an alarm	***6.3***
Topic 6.4 Alarm Access and Acknowledgement		
6.4.1	The process of clearing alarms interferes with monitoring and control operations	***6.4***
6.4.2	Controllers unintentionally clear important alarms when there are too many alarms that need to be cleared	***6.4***
6.4.3	It is difficult to sort alarms by priority, time of occurrence, or other useful dimensions	***6.4***
6.4.4	Previously acknowledged alarms are not immediately available (i.e., it takes two or more steps, screens, or keystrokes to access previously acknowledged alarms)	***6.4***
6.4.5	Controllers accidentally acknowledge or clear alarms for an adjacent console	***6.4***
Topic 6.5 Nuisance Alarms		
6.5.1	The number of nuisance alarms limits the ability to quickly identify potentially important alarms	***6.5***

PF ID	Performance Factor	HF Topic Risk Level Calculation
6.5.2	Monitoring and control operations are disrupted by a flood of alarms (e.g., triggered by conditions such as communications loss or equipment start-up)	***6.5***
6.5.3	Monitoring and control activities are disrupted by unnecessary information, alarms, or notifications being displayed on the alarm screen (e.g., action started, action completed, etc.)	***6.5***
6.5.4	Too many nuisance alarms are caused by equipment that is waiting to be fixed	***6.5***
6.5.5	Some alarms classified as critical do not represent true critical situations	***6.5***
Human Factors Area 7. Controller Training		
Topic 7.1 Pipeline Fundamentals Knowledge and Field Exposure		
7.1.1	Controller training does not adequately prepare Controllers to respond to all the situations that they are likely to encounter	***7.1***
7.1.2	Controller on-the-job training does not provide the optimal assignment of mentor(s) to ensure exposure to a sufficient range of expertise and good operating practices	***7.1***
7.1.3	Controllers are not provided adequate training about hydraulics	***7.1***
7.1.4	Controllers are not provided adequate training on field operations and field systems	***7.1***
7.1.5	Controllers are not adequately trained on specific console operations prior to working alone	***7.1***
7.1.6	Controllers are not provided refresher training frequently enough	***7.1***
7.1.7	Controllers are not provided adequate training before the introduction of a new pipeline	***7.1***
7.1.8	Controllers are not provided adequate training on a specific operational procedure, product, or tool before it is introduced into operation	***7.1***
Topic 7.2 Emergency Response Training		
7.2.1	Controllers are not adequately trained in *emergency response*	***7.2***
7.2.2	Controllers are not adequately trained in handling *abnormal* situations	***7.2***
Human Factors Area 8. Coping with Stress		
Topic 8.1 Abnormal Situation Task Assignments		
8.1.1	Controllers are distracted in their response to *abnormal* situations by non-critical, ongoing duties (e.g., responding to phone calls)	***8.1***
8.1.2	Controllers are distracted in their response to *abnormal* situations by the need to provide required notifications	***8.1***
8.1.3	Controllers are distracted in their response to *abnormal* situations by the need to continue to monitor and control unrelated, ongoing operations	***8.1***
8.1.4	Control room staff roles and responsibilities during *abnormal* situations are not well defined	***8.1***
Topic 8.2 Control Room Distractions		
8.2.1	Controllers are distracted from monitoring and controlling operations by the need to complete operations reports (e.g., operating sheets, production summaries, line status summaries)	***8.2***
8.2.2	Controllers end up completing work that is assigned to schedulers	***8.2***
8.2.3	Field personnel do not provide adequate or timely support to Controllers	***8.2***
8.2.4	Stressful relations with control room management distracts Controllers from monitoring and control operations	***8.2***

PF ID	Performance Factor	HF Topic Risk Level Calculation
8.2.5	Stress resulting from productivity goals, incentives, or penalties distracts Controllers from monitoring and control operations	***8.2***
Human Factors Area 9. Controller Alertness		
Topic 9.1 Controller Fatigue		
9.1.1	A Controller feels particularly drowsy or fatigued during early afternoon and/or early morning (e.g., around 2-5 am/pm)	***9.1***
9.1.2	A Controller feels drowsy or tired throughout most of a shift	***9.1***
9.1.3	A Controller feels fatigued at the end of a shift	***9.1***
Topic 9.2 Controller Schedule and Rest		
9.2.1	Controllers get insufficient sleep because of transitions in shift schedules from day to night or night to day	***9.2***
9.2.2	Controllers get insufficient sleep because of being called in to work a shift on short notice	***9.2***
9.2.3	Controllers get insufficient sleep because of overtime work	***9.2***
9.2.4	Controllers get insufficient sleep because of twelve hour shifts	***9.2***
9.2.5	Controllers get insufficient sleep because of ongoing understaffing	***9.2***
9.2.6	Controllers get insufficient sleep because of shift start times	***9.2***
Topic 9.3 Slow Work Periods		
9.3.1	Controllers experience reduced alertness during slow work periods	***9.3***
9.3.2	Controllers experience difficulty regaining alertness to deal with a challenging situation following a slow work period	***9.3***
Topic 9.4 Alertness Management Practices		
9.4.1	Controllers report to work tired enough that they are concerned about their ability to run the pipeline	***9.4***
9.4.2	Controllers do not notify management when they report to work without adequate rest	***9.4***
9.4.3	Controllers report for work tired because they have not been provided training on sleep basics, personal alertness practices, and effective fatigue-reduction practices	***9.4***
Human Factors Area 10. Automation		
Topic 10.1 Automated Operations		
10.1.1	Automation of control actions makes the Controller job more difficult	***10.1***
10.1.2	Too many steps are required to set up an automated sequence of control actions	***10.1***
10.1.3	Automated operation of some equipment conflicts or interferes with Controller actions	***10.1***
10.1.4	Controllers can forget to perform a manual control action because the initial steps are automated	***10.1***
10.1.5	Automation is not consistent across similar stations/locations	***10.1***
10.1.6	Controllers do not understand how automation works at a station/location	***10.1***
10.1.7	Controllers do not sufficiently trust the reliability of control action automation	***10.1***
10.1.8	There are some steps in an automated sequence that are not displayed by SCADA	***10.1***

PF ID	Performance Factor	HF Topic Risk Level Calculation
10.1.9	There are specific control actions (e.g., line ups, line shutdown, and manifold flushing) that would benefit from automation	***10.1***
Human Factors Area 11. Control Room Design and Staffing		
Topic 11.1 Control Room Design		
11.1.1	The location of break facilities keeps Controllers away from their console too long	***11.1***
11.1.2	The location of break facilities keeps Controllers from taking appropriate brief breaks	***11.1***
11.1.3	The lack of breaks during a shift makes it difficult to meet basic personal needs (i.e., food, bathroom, illness, etc.)	***11.1***
11.1.4	Controllers on break cannot be reached to address an immediate operational situation	***11.1***
Topic 11.2 Control Room Staffing		
11.2.1	Another Controller's long break times puts an excessive burden on the relieving Controller	***11.2***
11.2.2	Controller staffing is not adequate to cover for sudden problems (e.g., family emergencies, sudden serious illness, etc.)	***11.2***
11.2.3	Controller staffing is not adequate to allow for vacation, sick leave, and/or regularly scheduled days off	***11.2***
11.2.4	Controllers work on their scheduled day off because of required participation in extra activities (e.g., special projects, meetings, training, etc.)	***11.2***
11.2.5	Controller staffing is not adequate to provide Controller assistance during busy *normal* operations	***11.2***
11.2.6	Controller staffing is not adequate to provide Controller assistance during *abnormal* situations	***11.2***

APPENDIX D: CONTROLLER SURVEY RESULTS

Following is a representative set of results from the administration of the Controller Survey to 23 Controllers at one participating operator's control room. The results provide the 25th, 50th (median), and 75th percentile values for each Performance Factor from the Human Factors Taxonomy that used the same wording and prevalence response format in the trial application of the Controller Survey as the final version of the survey. In addition, the interquartile range – the range of scores from the 25th to 75th percentile – are provided as an index of inter-rater reliability for each Performance Factor. For the purposes of these ratings, the following scale and rating values were used. Note that questions which originally had a Yes/No format in the survey are not included in this table (e.g., 1.1.3).

0	1	2	3	4	5	6	7
Never	Once a year	Few times a year	Once a month	Once a week	Once a day	More than once a day	More than once an hour

PF #	Performance Factor	25th %	50th %	75th %	Interquartile Range
1.1.1	Execution of a control action (e.g., open/close valve, start/stop pump, change setpoint) requires too many steps (e.g., more than three)	0	5	7	7.00
1.1.2	Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex	5	7	7	2.00
1.1.4	Some equipment requires control actions that are different than similar equipment at the majority of locations	3	4	6	3.00
1.1.5	Some operations have a very small margin for error	5	7	7	2.00
1.2.1	Two or more control operations (e.g., line switches) must be done at the same time	5	6	7	2.00
1.2.2	Excessive telephone activity interferes with monitoring and control operations	6	6	7	1.00
1.2.3	Shift hand-off activities interfere with operations	3.5	4	5	1.50
1.2.4	Unusual work conditions (trainees, tours/visitors) interfere with operations	3	3	4	1.00
1.2.5	Unusual operational conditions (smart pigging, major repairs) interfere with operations	3.5	4	4	0.50
1.2.6	Controllers have to make important operational decisions without sufficient time to adequately consider alternatives	3	4	4	1.00
2.1.1	There are not enough display monitors to show all of the information that a Controller needs at one time during *normal* operations	3	5	6.5	3.50
2.1.2	There are not enough display monitors to show all of the information that a Controller needs at one time during *abnormal* situations	2	3	4	2.00
2.2.1	Inconsistencies in SCADA display design from screen to screen increase the difficulty of getting needed information	3	4	6	3.00
2.2.2	A cluttered, or complicated SCADA display increases the difficulty of finding needed information	3	4	4	1.00

PF #	Performance Factor	25th %	50th %	75th %	Interquartile Range
2.2.3	The layout of information (e.g., lines, equipment, and data) on the SCADA display increases the difficulty of finding, identifying, and interpreting information	2	4	4	2.00
2.2.4	Needed information is not shown on the appropriate SCADA display	3	3	4	1.00
2.2.6	Navigating between SCADA displays interferes with the flow of monitoring and control activities	0	3	4	4.00
2.2.7	The location or layout of SCADA control boxes/targets makes them difficult to use	3	4	6	3.00
2.3.1	Information about where the current SCADA display is within the pipeline system is not adequately provided	0	0	3	3.00
2.3.2	Some *colors* on SCADA displays make data interpretation difficult	0	2	4	4.00
2.3.3	Some *labels* on SCADA displays make data interpretation difficult	3	3	4	1.00
2.3.4	Some *symbols* on SCADA displays make data interpretation difficult	0	3	3	3.00
2.3.5	Controllers must transform values from the measurement scale presented on the SCADA display to another scale (e.g., psi to bar, gallons/min to liters/min, etc.) to complete a task	0	0	0	0.00
2.3.6	SCADA displays do not provide adequate system overview information for keeping track of system status	0	0	3	3.00
2.3.7	There is inconsistent use of units of measure (e.g., gallons, barrels, cubic meters) on SCADA displays	0	0	0	0.00
3.1.1	Shift hand-off procedures or tools do not adequately identify, track, and record information required by the Controller coming on shift	0	0	3	3.00
3.1.2	Formal shift hand-off procedures are not adequately followed by Controllers	3	3	4	1.00
3.2.1	The exchange of required operations information between Controllers on different consoles is not adequate	0	3	3	3.00
3.2.2	Control center staff (not including field technicians) are not available to provide assistance with an operational issue when required	2	3	6	4.00
3.2.3	The lines of communication in the control room are not clearly defined or adhered to	2	3	4	2.00
3.3.1	Product delivery schedules are inaccurate	4	5	5	1.00
3.3.2	Changes in product delivery schedules are not communicated to Controllers at all	3	3	3	0.00
3.3.3	Changes in product delivery schedules are communicated to Controllers without sufficient lead time	3	3	4	1.00
3.4.2	Important field information (e.g., operational and maintenance activities) is not provided directly to Controllers in a timely manner	3	3	4	1.00
3.4.3	Field personnel communicate incorrect information about equipment (e.g., pumps and valves) status to Controllers	0	3	3	3.00
3.4.4	Field personnel do not fully communicate important ongoing operational conditions (e.g., pigging or repairs) to Controllers	3	3	4	1.00
3.4.5	Controllers have difficulty communicating with field personnel due to a lack of available communications equipment	3	3	6	3.00

PF #	Performance Factor	25th %	50th %	75th %	Interquartile Range
4.1.1	SCADA data from field instruments (meters, gauges, etc.) are inaccurate	4	5	7	3.00
4.1.2	SCADA data are stale/out-of-date, or unavailable due to a communications problem (e.g., outage, time delay)	5	6	7	2.00
4.1.3	The SCADA display does not indicate that data are out-of-date or unavailable	3	6	4.5	1.50
4.1.4	Changes in field system operational status (e.g., equipment identity or operational activities) are not adequately indicated in SCADA displays	3	3	4	1.00
4.1.5	Displayed pipeline schematics or operational parameters (e.g., MOPs) are inaccurate	3	3	4	1.00
4.1.6	Manually entered batch, log, and/or summary information is not accurate	3	4	4.5	1.50
4.1.7	Required information is not available in the SCADA display	2	3	5	3.00
5.1.1	When to use a procedure is not clearly defined	2	3	3	1.00
5.1.2	Required technical detail is not provided by a procedure	0	3	3	3.00
5.1.3	Procedures are difficult to read	0	3	3	3.00
5.1.4	Critical information is difficult to find in a procedure	2	3	4	2.00
5.1.5	Procedures do not meet the needs of both novice and experienced operators	0	3	3	3.00
5.1.6	Procedures and job aids used in responding to *abnormal* situations are difficult to follow	0	2	3	3.00
5.2.1	A specific required operations procedure is not available	0	2	3	3.00
5.2.3	Procedures and job aids required to identify and recover from *abnormal* situations are not readily available	0	3	4	4.00
5.3.1	Procedures contain out-of-date or inaccurate information	2	3	4	2.00
5.3.2	Procedure update notifications are not adequately provided to Controllers	0	2	3	3.00
5.3.3	Controllers do not understand the documented procedure	0	2	3	3.00
5.3.4	Controllers execute actions in a manner that is not consistent with established and documented procedures because the procedure is incorrect or incomplete	0	2	3	3.00
6.1.1	No alarm is available to notify the Controller about important current operational status information (e.g., pressure or batch interface at a specific point in the line)	0	0	3	3.00
6.1.2	Alarms do not provide the Controller with sufficient lead time to take corrective actions (i.e., because of sensor location)	0	3	3	3.00
6.1.3	Changes in operating conditions triggered by external events that are outside of Controllers' influence (e.g., equipment failure or maintenance on a feeder system) are not displayed on the SCADA	0	3	3	3.00
6.2.1	Alarm displays become too cluttered making it difficult to identify important alarms	3	3	5.5	2.50
6.2.2	The alarm display shows alarms from another console and Controllers have difficulty finding the alarms for their console	3	4.5	6	3.00
6.2.3	High-priority alarms are ineffective in attracting a Controller's attention when performing other activities	0	0	3	3.00

PF #	Performance Factor	25th %	50th %	75th %	Interquartile Range
6.2.4	The sound or loudness of critical alarms startles Controllers unnecessarily	3	6	7	4.00
6.2.5	The *sound* of an alarm does not clearly indicate the intended alarm priority	0	0	2	2.00
6.2.6	The *color* of an alarm does not clearly indicate the intended alarm priority	0	0	2	2.00
6.3.1	The displayed alarm description is difficult to interpret	3	6	5.5	2.50
6.3.2	There are multiple causes for some alarms, but insufficient information is provided to identify the actual cause	3	3	4	1.00
6.3.3	Alarm summary information does not provide adequate information about conditions at the time that the alarm was triggered	0	3	3	3.00
6.3.4	Alarms are not displayed in a consistent format, making their interpretation difficult	0	3	3	3.00
6.4.1	The process of clearing alarms interferes with monitoring and control operations	3	5	6	3.00
6.4.2	Controllers unintentionally clear important alarms when there are too many alarms that need to be cleared	3	5	6	3.00
6.4.3	It is difficult to sort alarms by priority, time of occurrence, or other useful dimensions	0	2	3	3.00
6.4.5	Controllers accidentally acknowledge or clear alarms for an adjacent console	5	6	7	2.00
6.5.2	Monitoring and control operations are disrupted by a flood of alarms (e.g., triggered by conditions such as communications loss or equipment start-up)	4	5	5	1.00
6.5.3	Monitoring and control activities are disrupted by unnecessary information alarms, or notifications being displayed on the alarm screen (e.g., action started, action completed, etc.)	2	2	2	0.00
6.5.5	Some alarms classified as critical do not represent true critical situations	3	3	4.5	1.50
7.1.8	Controllers are not provided adequate training on a specific operational procedure, product, or tool before it is introduced into operation	0	3	3	3.00
8.2.1	Controllers are distracted from monitoring and controlling operations by the need to complete operations reports (e.g., operating sheets, production summaries, line status summaries)	3	4	5	2.00
8.2.2	Controllers end up completing work that is assigned to schedulers	5	5	6	1.00
8.2.3	Field personnel do not provide adequate or timely support to Controllers	3	3	4	1.00
8.2.4	Stressful relations with control room management distracts Controllers from monitoring and control operations	0	3	4	4.00
8.2.5	Stress resulting from productivity goals, incentives, or penalties distracts Controllers from monitoring and control operations	0	3	4	4.00
9.1.1	A Controller feels particularly drowsy or fatigued during early afternoon and/or early morning (e.g., around 2-5 am/pm)	3	4	5	2.00
9.1.2	A Controller feels drowsy or tired throughout most of a shift	2	3	4	2.00
9.1.3	A Controller feels fatigued at the end of a shift	3	4	5	2.00

PF #	Performance Factor	25th %	50th %	75th %	Interquartile Range
9.2.1	Controllers get insufficient sleep because of transitions in shift schedules from day to night or night to day	0	3	4	4.00
9.2.2	Controllers get insufficient sleep because of being called in to work a shift on short notice	0	3	3	3.00
9.2.3	Controllers get insufficient sleep because of overtime work	0	3	4	4.00
9.2.4	Controllers get insufficient sleep because of twelve hour shifts	0	3	4	4.00
9.2.5	Controllers get insufficient sleep because of ongoing understaffing	0	3	4	4.00
9.2.6	Controllers get insufficient sleep because of shift start times	0	3	5	5.00
9.3.1	Controllers experience reduced alertness during slow work periods	3	3	4	1.00
9.3.2	Controllers experience difficulty regaining alertness to deal with a challenging situation following a slow work period	0	0	3	3.00
10.1.2	Too many steps are required to set up an automated sequence of control actions	0	3	3	3.00
10.1.3	Automated operation of some equipment conflicts or interferes with Controller actions	0	3	3	3.00
10.1.4	Controllers can forget to perform a manual control action because the initial steps are automated	0	2	3	3.00
10.1.5	Automation is not consistent across similar stations/locations	3	4	6	3.00
10.1.6	Controllers do not understand how automation works at a station/location	0	2	3	3.00
10.1.7	Controllers do not sufficiently trust the reliability of control action automation	3	3	5.5	2.50
10.1.8	There are some steps in an automated sequence that are not displayed by SCADA	0	2	3	3.00
10.1.9	There are specific control actions (e.g., line ups, line shutdown, and manifold flushing) that would benefit from automation	0	3	3	3.00
11.1.4	Controllers on break cannot be reached to address an immediate operational situation	0	3	4	4.00
11.2.1	Another Controller's long break times puts an excessive burden on the relieving Controller	0	3	3	3.00
11.2.2	Controller staffing is not adequate to cover for sudden problems (e.g., family emergencies, sudden serious illness, etc.)	3	3	4	1.00
11.2.3	Controller staffing is not adequate to allow for vacation, sick leave, and/or regularly scheduled days off	3	3	4	1.00
11.2.4	Controllers work on their scheduled day off because of required participation in extra activities (e.g., special projects, meetings, training, etc.)	3	3	4	1.00
11.2.5	Controller staffing is not adequate to provide Controller assistance during busy *normal* operations	2	3	3	1.00

APPENDIX E: RISK LIKELIHOOD RATING RESULTS

Following are the results from the administration of the Risk Likelihood rating activity to 24 experienced operators from the seven participating pipeline companies. The results provide the 25th, 50th (median), and 75th percentile values for each Performance Factor from the Human Factors Taxonomy. In addition, the interquartile range – the range of scores from the 25th to 75th percentile – are provided as an index of inter-rater reliability for each Performance Factor. All Performance Factors from the final Human Factors Taxonomy were included in this initial application of the Risk Likelihood rating activity. For the purposes of these ratings, the following scale and rating values were used.

Risk Likelihood Response Category	Risk Likelihood Rating Value
Not significant	1
Low	2
Medium	3
High	4
Very High	5

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
1.1.1	Execution of a control action (e.g., open/close valve, start/stop pump, change setpoint) requires too many steps (e.g., more than three)	2	2	3	1.00
1.1.2	Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex	2	3	3	1.00
1.1.3	Controllers make errors in performing manual calculations that are used directly as an input to operational activities	3	3.5	4	1.00
1.1.4	Some equipment requires control actions that are different than similar equipment at the majority of locations	2	3	3	1.00
1.1.5	Some operations have a very small margin for error	3	3	4	1.00
1.2.1	Two or more control operations (e.g., line switches) must be done at the same time	3	3	4	1.00
1.2.2	Excessive telephone activity interferes with monitoring and control operations	3	3	4	1.00
1.2.3	Shift hand-off activities interfere with operations	2	2	3	1.00
1.2.4	Unusual work conditions (trainees, tours/visitors) interfere with operations	2	2	3	1.00
1.2.5	Unusual operational conditions (smart pigging, major repairs) interfere with operations	2.25	3	3	0.75
1.2.6	Controllers have to make important operational decisions without sufficient time to adequately consider alternatives	3	3	4	1.00

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
2.1.1	There are not enough display monitors to show all of the information that a Controller needs at one time during *normal* operations	2	2	3	1.00
2.1.2	There are not enough display monitors to show all of the information that a Controller needs at one time during *abnormal* situations	2	3	4	2.00
2.1.3	Monitoring and control activities are disrupted by inadequate display monitor placement (e.g., too low, too high, or positioned so that there is screen glare)	2	2	3	1.00
2.1.4	Monitoring and control activities are disrupted by inadequate monitor display quality (e.g., clarity, brightness, contrast)	2	2	3	1.00
2.2.1	Inconsistencies in SCADA display design from screen to screen increase the difficulty of getting needed information	2	3	3	1.00
2.2.2	A cluttered, or complicated SCADA display increases the difficulty of finding needed information	2.25	3	4	1.75
2.2.3	The layout of information (e.g., lines, equipment, and data) on the SCADA display increases the difficulty of finding, identifying, and interpreting information	2	3	3.75	1.75
2.2.4	Needed information is not shown on the appropriate SCADA display	3	4	4	1.00
2.2.5	Controllers must navigate between more than two SCADA displays to view related information	2	3	3.75	1.75
2.2.6	Navigating between SCADA displays interferes with the flow of monitoring and control activities	1.25	2	3.75	2.50
2.2.7	The location or layout of SCADA control boxes/targets makes them difficult to use	2	2	3	1.00
2.3.1	Information about which part of the pipeline system the current SCADA display represents is not adequately provided	2	3	3.75	1.75
2.3.2	Some *colors* on SCADA displays make data interpretation difficult	2	2	3	1.00
2.3.3	Some *labels* on SCADA displays make data interpretation difficult	2	2	3	1.00
2.3.4	Some *symbols* on SCADA displays make data interpretation difficult	2	2	3	1.00
2.3.5	Controllers must transform values from the measurement scale presented on the SCADA display to another scale (e.g., psi to bar, gallons/min to liters/min, etc.) to complete a task	2	3	3	1.00
2.3.6	SCADA displays do not provide adequate system overview information for keeping track of system status	2	3	4	2.00
2.3.7	There is inconsistent use of units of measure (e.g., gallons, barrels, cubic meters) on SCADA displays	2	2	3	1.00
3.1.1	Shift hand-off procedures or tools do not adequately identify, track, and record information required by the Controller coming on shift	2	3	4	2.00
3.1.2	Formal shift hand-off procedures are not adequately followed by Controllers	2.25	3	3	0.75

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
3.2.1	The exchange of required operations information between Controllers on different consoles is not adequate	2	3	3.75	1.75
3.2.2	Control center staff (not including field technicians) are not available to provide assistance with an operational issue when required	3	3.5	4	1.00
3.2.3	The lines of communication in the control room are not clearly defined or adhered to	2	2.5	3	1.00
3.3.1	Product delivery schedules are inaccurate	3	3	4	1.00
3.3.2	Changes in product delivery schedules are not communicated to Controllers at all	3	4	5	2.00
3.3.3	Changes in product delivery schedules are communicated to Controllers without sufficient lead time	3	3.5	4	1.00
3.4.1	Field technicians are not available to assist Controllers with an operational issue when required	3	3	4	1.00
3.4.2	Important field information (e.g., operational and maintenance activities) is not provided directly to Controllers in a timely manner	3	3	4	1.00
3.4.3	Field personnel communicate incorrect information about equipment (e.g., pumps and valves) status to Controllers	3	4	4	1.00
3.4.4	Field personnel do not fully communicate important ongoing operational conditions (e.g., pigging or repairs) to Controllers	3	3.5	4.75	1.75
3.4.5	Controllers have difficulty communicating with field personnel due to a lack of available communications equipment	2	3	3	1.00
4.1.1	SCADA data from field instruments (meters, gauges, etc.) are inaccurate	3	4	4	1.00
4.1.2	SCADA data are stale/out-of-date, or unavailable due to a communications problem (e.g., outage, time delay)	2.25	3	4	1.75
4.1.3	The SCADA display does not indicate that data are out-of-date or unavailable	2	4	5	3.00
4.1.4	Changes in field system operational status (e.g., equipment identity or operational activities) are not adequately indicated in SCADA displays	3	3	4.75	1.75
4.1.5	Displayed pipeline schematics or operational parameters (e.g., MOPs) are inaccurate	3	4	5	2.00
4.1.6	Manually entered batch, log, and/or summary information is not accurate	2	4	4	2.00
4.1.7	Required information is not available on the SCADA display	3	4	4	1.00
5.1.1	When to use a procedure is not clearly defined	3	3	4	1.00
5.1.2	Required technical detail is not provided by a procedure	2	3	3.75	1.75
5.1.3	Procedures are difficult to read	2	3	3.75	1.75
5.1.4	Critical information is difficult to find in a procedure	3	3	4	1.00
5.1.5	Procedures do not meet the needs of both novice and experienced operators	3	3	4	1.00
5.1.6	Procedures and job aids used in responding to *abnormal* situations are difficult to follow	3	4	4	1.00

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
5.2.1	A specific required operations procedure is not available	3	3.5	4	1.00
5.2.2	Finding an individual procedure among the large overall number of procedures is difficult	2	3	3	1.00
5.2.3	Procedures and job aids required to identify and recover from *abnormal* situations are not readily available	3	4	4	1.00
5.3.1	Procedures contain out-of-date or inaccurate information	3	3.5	4.75	1.75
5.3.2	Procedure update notifications are not adequately provided to Controllers	3	3	4	1.00
5.3.3	Controllers do not understand the documented procedure	3	4	4.75	1.75
5.3.4	Controllers execute actions in a manner that is not consistent with established and documented procedures because the procedure is incorrect or incomplete	3.25	4	4	0.75
6.1.1	No alarm is available to notify the Controller about important current operational status information (e.g., pressure or batch interface at a specific point in the line)	3	5	5	2.00
6.1.2	Alarms do not provide the Controller with sufficient lead time to take corrective actions (i.e., because of sensor location)	3	4	4	1.00
6.1.3	Changes in operating conditions triggered by external events that are outside of Controllers' influence (e.g., equipment failure or maintenance on a feeder system) are not displayed on the SCADA	2	3	4	2.00
6.2.1	Alarm displays become too cluttered making it difficult to identify important alarms	3	3	4	1.00
6.2.2	The alarm display shows alarms from another console and Controllers have difficulty finding the alarms for their console	2	3	4	2.00
6.2.3	High-priority alarms are ineffective in attracting a Controller's attention when performing other activities	3	4	5	2.00
6.2.4	The sound or loudness of critical alarms startles Controllers unnecessarily	1	2	2	1.00
6.2.5	The *sound* of an alarm does not clearly indicate the intended alarm priority	1	2	3	2.00
6.2.6	The *color* of an alarm does not clearly indicate the intended alarm priority	2	2	3.75	1.75
6.3.1	The displayed alarm description is difficult to interpret	2	3	4	2.00
6.3.2	There are multiple causes for some alarms, but insufficient information is provided to identify the actual cause	2	3	3	1.00
6.3.3	Alarm summary information does not provide adequate information about conditions at the time that the alarm was triggered	2	3	3	1.00
6.3.4	Alarms are not displayed in a consistent format, making their interpretation difficult	2	3	3.75	1.75
6.3.5	It is difficult to determine the intended priority of an alarm	2.25	3	4	1.75
6.4.1	The process of clearing alarms interferes with monitoring and control operations	2	2	3	1.0
6.4.2	Controllers unintentionally clear important alarms when there are too many alarms that need to be cleared	3	3.5	4.75	1.75

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
6.4.3	It is difficult to sort alarms by priority, time of occurrence, or other useful dimensions	2	3	3	1.00
6.4.4	Previously acknowledged alarms are not immediately available (i.e., it takes two or more steps, screens, or keystrokes to access previously acknowledged alarms)	2	3	4	2.00
6.4.5	Controllers accidentally acknowledge or clear alarms for an adjacent console	1.25	4	5	3.75
6.5.1	The number of nuisance alarms limits the ability to quickly identify potentially important alarms	3	4	4	1.00
6.5.2	Monitoring and control operations are disrupted by a flood of alarms (e.g., triggered by conditions such as communications loss or equipment start-up)	3	3	3.75	0.75
6.5.3	Monitoring and control activities are disrupted by unnecessary information, alarms, or notifications being displayed on the alarm screen (e.g., action started, action completed, etc.)	2	3	3	1.00
6.5.4	Too many nuisance alarms are caused by equipment that is waiting to be fixed	2.25	3	4	1.75
6.5.5	Some alarms classified as critical do not represent true critical situations	2	2	3	1.00
7.1.1	Controller training does not adequately prepare Controllers to respond to all the situations that they are likely to encounter	3	4	4	1.00
7.1.2	Controller on-the-job training does not provide the optimal assignment of mentor(s) to ensure exposure to a sufficient range of expertise and good operating practices	3	4	4	1.00
7.1.3	Controllers are not provided adequate training about hydraulics	3	3.5	4.75	1.75
7.1.4	Controllers are not provided adequate training on field operations and field systems	2	3	3	1.00
7.1.5	Controllers are not adequately trained on specific console operations prior to working alone	4	4.5	5	1.00
7.1.6	Controllers are not provided refresher training frequently enough	3	3	4	1.00
7.1.7	Controllers are not provided adequate training before the introduction of a new pipeline	3	4	4.75	1.75
7.1.8	Controllers are not provided adequate training on a specific operational procedure, product, or tool before it is introduced into operation	3	4	4.75	1.75
7.2.1	Controllers are not adequately trained in *emergency response*	4	4	5	1.00
7.2.2	Controllers are not adequately trained in handling *abnormal* situations	4	4	5	1.00
8.1.1	Controllers are distracted in their response to *abnormal* situations by non-critical, ongoing duties (e.g., responding to phone calls)	2	3	3	1.00
8.1.2	Controllers are distracted in their response to *abnormal* situations by the need to provide required notifications	2	3	3	1.00

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
8.1.3	Controllers are distracted in their response to *abnormal* situations by the need to continue to monitor and control unrelated, ongoing operations	3	3	3	0.00
8.1.4	Control room staff roles and responsibilities during *abnormal* situations are not well defined	2	3	3.75	1.75
8.2.1	Controllers are distracted from monitoring and controlling operations by the need to complete operations reports (e.g., operating sheets, production summaries, line status summaries)	2	2	3	1.00
8.2.2	Controllers end up completing work that is assigned to schedulers	2	2	3	1.00
8.2.3	Field personnel do not provide adequate or timely support to Controllers	2	3	3	1.00
8.2.4	Stressful relations with control room management distracts Controllers from monitoring and control operations	1.25	2	2	0.75
8.2.5	Stress resulting from productivity goals, incentives, or penalties distracts Controllers from monitoring and control operations	1	2	3	2.00
9.1.1	A Controller feels particularly drowsy or fatigued during early afternoon and/or early morning (e.g., around 2-5 am/pm)	3	3	4	1.00
9.1.2	A Controller feels drowsy or tired throughout most of a shift	2.25	3.5	4	1.75
9.1.3	A Controller feels fatigued at the end of a shift	2	3	3	1.00
9.2.1	Controllers get insufficient sleep because of transitions in shift schedules from day to night or night to day	2	3	3	1.00
9.2.2	Controllers get insufficient sleep because of being called in to work a shift on short notice	3	3	4	1.00
9.2.3	Controllers get insufficient sleep because of overtime work	2	3	4	2.00
9.2.4	Controllers get insufficient sleep because of twelve hour shifts	2	2	2.75	0.75
9.2.5	Controllers get insufficient sleep because of ongoing understaffing	3	3	4	1.00
9.2.6	Controllers get insufficient sleep because of shift start times	2	2	3	1.00
9.3.1	Controllers experience reduced alertness during slow work periods	2	2.5	3	1.00
9.3.2	Controllers experience difficulty regaining alertness to deal with a challenging situation following a slow work period	2	3	3	1.00
9.4.2	Controllers do not notify management when they report to work without adequate rest	2	2	3	1.00
9.4.3	Controllers report for work tired because they have not been provided training on sleep basics, personal alertness practices, and effective fatigue-reduction practices	2	2	3	1.00
10.1.1	Automation of control actions makes the Controller job more difficult	1	2	2	1.00
10.1.2	Too many steps are required to set up an automated sequence of control actions	2	2	2.75	0.75
10.1.3	Automated operation of some equipment conflicts or interferes with Controller actions	2	2	3	1.00

PF ID	Performance Factor	25th %	50th %	75th %	Interquartile Range
10.1.4	Controllers can forget to perform a manual control action because the initial steps are automated	2	3	3	1.00
10.1.5	Automation is not consistent across similar stations/locations	2	3	3.75	1.75
10.1.6	Controllers do not understand how automation works at a station/location	3	3	4	1.00
10.1.7	Controllers do not sufficiently trust the reliability of control action automation	2	2.5	3	1.00
10.1.8	There are some steps in an automated sequence that are not displayed by SCADA	2	2	3	1.00
10.1.9	There are specific control actions (e.g., line ups, line shutdown, and manifold flushing) that would benefit from automation	2	2	3.75	1.75
11.1.1	The location of break facilities keeps Controllers away from their console too long	2	2.5	3	1.00
11.1.2	The location of break facilities keeps Controllers from taking appropriate brief breaks	1.25	2	3	1.75
11.1.3	The lack of breaks during a shift makes it difficult to meet basic personal needs (i.e., food, bathroom, illness, etc.)	2	2.5	3	1.0
11.1.4	Controllers on break cannot be reached to address an immediate operational situation	2.25	4	5	2.75
11.2.1	Another Controller’s long break times puts an excessive burden on the relieving Controller	2	3	4	2.00
11.2.2	Controller staffing is not adequate to cover for sudden problems (e.g., family emergencies, sudden serious illness, etc.)	3	4	4.75	1.75
11.2.3	Controller staffing is not adequate to allow for vacation, sick leave, and/or regularly scheduled days off	3	4	4	1.00
11.2.4	Controllers work on their scheduled day off because of required participation in extra activities (e.g., special projects, meetings, training, etc.)	2.25	3	3	0.75
11.2.5	Controller staffing is not adequate to provide Controller assistance during busy *normal* operations	2	3	3	1.00
11.2.6	Controller staffing is not adequate to provide Controller assistance during *abnormal* situations	3	3	4	1.00

APPENDIX F: PRELIMINARY RISK LEVEL ANALYSIS RESULTS

Prevalence and Risk Likelihood categorical responses were transformed into the corresponding scores based on the assignments summarized in the tables below.

Prevalence and Risk Likelihood Response Categories and Score Scales

Prevalence Response Category	Prevalence Score Scale
Never	0
Once a Year	1
Few Times a Year	2
Once a Month	10
Once a Week	50
Once a Day	200
More than Once a Day	500
More than Once an Hour	2,000

Risk Likelihood Response Category	Risk Likelihood Score Scale
Not significant	1
Low	10
Medium	200
High	500
Very High	2,000

The following table provides the Prevalence Score, Risk Likelihood Score, Risk Level Score, and Risk Level Ranking by Performance Factor obtained from the trial applications of the Controller Survey and Risk Likelihood rating activity. These results are based on the combined first-generation Controller Survey data obtained from 222 Controllers from the seven participating companies and the trial application of the Risk Likelihood rating activity to 24 operational experts from those companies. Note that Prevalence Score values for Yes/No items were approximated based on an algorithm developed to score the initial test version of the Controller Survey; whereas the final form of the Survey does not have any Yes/No items (see note at the end of the table). Also, Performance Factors that ended up with the same Risk Level Score were all assigned the same Risk Level Ranking.

Prevalence Score, Risk Likelihood Score, Risk Level Score, and Risk Level Ranking by Performance Factor obtained from the Trial Application of the Controller Survey and Risk Likelihood Rating Activity

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
1.1.1	Execution of a control action (e.g., open/close valve, start/stop pump, change setpoint) requires too many steps (e.g., more than three)	10	10	100	96
1.1.2	Routine activities (e.g., line start up, batch cutting, or manifold flushing) are too complex	50	200	10000	13
1.1.3	Controllers make errors in performing manual calculations that are used directly as an input to operational activities	500	350	175000	6

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
1.1.4	Some equipment requires control actions that are different than similar equipment at the majority of locations	2	200	400	53
1.1.5	Some operations have a very small margin for error	50	200	10000	13
1.2.1	Two or more control operations (e.g., line switches) must be done at the same time	50	200	10000	13
1.2.2	Excessive telephone activity interferes with monitoring and control operations	200	200	40000	8
1.2.3	Shift hand-off activities interfere with operations	2	10	20	97
1.2.4	Unusual work conditions (trainees, tours/visitors) interfere with operations	2	10	20	97
1.2.5	Unusual operational conditions (smart pigging, major repairs) interfere with operations	2	200	400	53
1.2.6	Controllers have to make important operational decisions without sufficient time to adequately consider alternatives	2	200	400	53
2.1.1	There are not enough display monitors to show all of the information that a Controller needs at one time during *normal* operations	2	10	20	97
2.1.2	There are not enough display monitors to show all of the information that a Controller needs at one time during *abnormal* situations	1	200	200	85
‡2.1.3	Monitoring and control activities are disrupted by inadequate display monitor placement (e.g., too low, too high, or positioned so that there is screen glare)	50	10	500	45
‡2.1.4	Monitoring and control activities are disrupted by inadequate monitor display quality (e.g., clarity, brightness, contrast)	0	10	0	116
2.2.1	Inconsistencies in SCADA display design from screen to screen increase the difficulty of getting needed information	2	200	400	53
2.2.2	A cluttered, or complicated SCADA display increases the difficulty of finding needed information	2	200	400	53
2.2.3	The layout of information (e.g., lines, equipment, and data) on the SCADA display increases the difficulty of finding, identifying, and interpreting information	1	200	200	85
2.2.4	Needed information is not shown on the appropriate SCADA display	2	500	1000	29
2.2.5	Controllers must navigate between more than two SCADA displays to view related information	10	200	2000	20
2.2.6	Navigating between SCADA displays interferes with the flow of monitoring and control activities	1	10	10	109
2.2.7	The location or layout of SCADA control boxes/targets makes them difficult to use	1	10	10	109
2.3.1	Information about which part of the pipeline system the current SCADA display represents is not adequately provided	0	200	0	116
2.3.2	Some *colors* on SCADA displays make interpretation difficult	0	10	0	116

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
2.3.3	Some *labels* on SCADA displays make interpretation difficult	1	10	10	109
2.3.4	Some *symbols* on SCADA displays make interpretation difficult	1	10	10	109
2.3.5	Controllers must transform values from the measurement scale presented on the SCADA display to another scale (e.g., psi to bar, gallons/min to liters/min, etc.) to complete a task	0	200	0	116
2.3.6	SCADA displays do not provide adequate system overview information for keeping track of system status	0	200	0	116
2.3.7	There is inconsistent use of units of measure (e.g., gallons, barrels, cubic meters) on SCADA displays	0	10	0	116
3.1.1	Shift hand-off procedures or tools do not adequately identify, track, and record information required by the Controller coming on shift	1	200	200	85
3.1.2	Formal shift hand-off procedures are not adequately followed by Controllers	2	200	400	53
3.2.1	The exchange of required operations information between Controllers on different consoles is not adequate	2	200	400	53
3.2.2	Control center staff (not including field technicians) are not available to provide assistance with an operational issue when required	2	350	700	38
3.2.3	The lines of communication in the control room are not clearly defined or adhered to	2	105	210	82
3.3.1	Product delivery schedules are inaccurate	2	200	400	53
3.3.2	Changes in product delivery schedules are not communicated to Controllers at all	2	500	1000	29
3.3.3	Changes in product delivery schedules are communicated to Controllers without sufficient lead time	2	350	700	38
3.4.1	Field technicians are not available to assist Controllers with an operational issue when required	2	200	400	53
3.4.2	Important information (e.g., operational and maintenance activities) is not provided directly to Controllers in a timely manner	2	200	400	53
3.4.3	Field personnel communicate incorrect information about equipment (e.g., pumps and valves) status to Controllers	2	500	1000	29
3.4.4	Field personnel do not fully communicate important ongoing operational conditions (e.g., pigging or repairs) to Controllers	2	350	700	38
3.4.5	Controllers have difficulty communicating with field personnel due to a lack of available communications equipment	2	200	400	53
4.1.1	SCADA data from field instruments (meters, gauges, etc) are inaccurate	10	500	5000	17
4.1.2	SCADA data are stale/out-of-date, or unavailable due to a communications problem (e.g., outage, time delay)	10	200	2000	20

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
4.1.3	The SCADA display does not indicate that data are out-of-date or unavailable	2	500	1000	29
4.1.4	Changes in field system operational status (e.g., equipment identity or operational activities) are not adequately indicated on SCADA displays	2	200	400	53
4.1.5	Displayed pipeline schematics or operational parameters (e.g., MOPs) are inaccurate	2	500	1000	29
4.1.6	Manually entered batch, log, and/or summary information is not accurate	2	500	1000	29
4.1.7	Required information is not available on the SCADA display	2	500	1000	29
5.1.1	When to use a procedure is not clearly defined	2	200	400	53
5.1.2	Required technical detail is not provided by a procedure	2	200	400	53
5.1.3	Procedures are difficult to read	1	200	200	85
5.1.4	Critical information is difficult to find in a procedure	1	200	200	85
5.1.5	Procedures do not meet the needs of both novice and experienced operators	2	200	400	53
5.1.6	Procedures and job aids used in responding to *abnormal* situations are difficult to follow	1	500	500	45
5.2.1	A specific required operations procedure is not available	1	350	350	81
5.2.2	Finding an individual procedure among the large overall number of procedures is difficult	2	200	400	53
5.2.3	Procedures and job aids required to identify and recover from *abnormal* situations are not readily available	0	500	0	116
5.3.1	Procedures contain out-of-date or inaccurate information	2	350	700	38
5.3.2	Procedure update notifications are not adequately provided to Controllers	1	200	200	85
5.3.3	Controllers do not understand the documented procedure	0	500	0	116
5.3.4	Controllers execute actions in a manner that is not consistent with established and documented procedures because the procedure is incorrect or incomplete	1	500	500	45
6.1.1	No alarm is available to notify the Controller about important operational status information (e.g., pressure or batch interface at a specific point in the line)	1	2000	2000	20
6.1.2	Alarms do not provide the Controller with sufficient lead time to take corrective actions (i.e., because of sensor location)	1	500	500	45
6.1.3	Changes in operating conditions triggered by external events that are outside of Controllers' influence (e.g., equipment failure or maintenance on a feeder system) are not displayed on the SCADA	2	200	400	53
6.2.1	Alarm displays become too cluttered making it difficult to identify important alarms	2	200	400	53
6.2.2	The alarm display shows alarms from another console and Controllers have difficulty finding the alarms for their console	0	200	0	116

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
6.2.3	High-priority alarms are ineffective in attracting a Controller's attention when performing other activities	0	500	0	116
6.2.4	The sound or loudness of critical alarms startles Controllers unnecessarily	0	10	0	116
6.2.5	The *sound* of an alarm does not clearly indicate the intended alarm priority	0	10	0	116
6.2.6	The *color* of an alarm does not clearly indicate the intended alarm priority	0	10	0	116
6.3.1	The displayed alarm description is difficult to interpret	1	200	200	85
6.3.2	There are multiple causes for some alarms, but insufficient information is provided to identify the actual cause	1	200	200	85
6.3.3	Alarm summary information does not provide adequate information about conditions at the time that the alarm was triggered	1	200	200	85
6.3.4	Alarms are not displayed in a consistent format, making their interpretation difficult	0	200	0	116
‡6.3.5	It is difficult to determine the intended priority of an alarm	1	200	200	85
6.4.1	The process of clearing alarms interferes with monitoring and control operations	2	10	20	97
6.4.2	Controllers unintentionally clear important alarms when there are too many alarms that need to be cleared	2	350	700	38
6.4.3	It is difficult to sort alarms by priority, time of occurrence, or other useful dimensions	0	200	0	116
‡6.4.4	Previously acknowledged alarms are not immediately available (i.e., it takes two or more steps, screens, or keystrokes to access previously acknowledged alarms)	200	200	40000	8
6.4.5	Controllers accidentally acknowledge or clear alarms for an adjacent console	1	500	500	45
‡6.5.1	The number of nuisance alarms limits the ability to quickly identify potentially important alarms	2000	500	1000000	1
6.5.2	Monitoring and control operations are disrupted by a flood of alarms (e.g., triggered by conditions such as communications loss or equipment start-up)	2	200	400	53
‡6.5.3	Monitoring and control activities are disrupted by unnecessary information alarms, or notifications being displayed on the alarm screen (e.g., action started, action completed, etc)	2000	200	400000	2
‡6.5.4	Too many nuisance alarms are caused by equipment that is waiting to be fixed	50	200	10000	13
6.5.5	Some alarms classified as critical do not represent true critical situations	2	10	20	97
‡7.1.1	Controller training does not adequately prepare Controllers to respond to all the situations that they are likely to encounter	200	500	100000	7
‡7.1.3	Controllers are not provided adequate training about hydraulics	10	350	3500	18

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
‡7.1.4	Controllers are not provided adequate training on field operations and field systems	10	200	2000	20
‡7.1.5	Controllers are not adequately trained on specific console operations prior to working alone	2	1250	2500	19
‡7.1.6	Controllers are not provided refresher training frequently enough	2	200	400	53
‡7.1.7	Controllers are not provided adequate training before the introduction of a new pipeline	500	500	250000	5
7.1.8	Controllers are not provided adequate training on a specific operational procedure, product, or tool before it is introduced into operation	1	500	500	45
‡7.2.1	Controllers are not adequately trained in *emergency response*	1	500	500	45
‡7.2.2	Controllers are not adequately trained in handling *abnormal* situations	0	500	0	116
‡8.1.1	Controllers are distracted in their response to *abnormal* situations by non-critical, ongoing duties (e.g., responding to phone calls)	2000	200	400000	2
‡8.1.2	Controllers are distracted in their response to *abnormal* situations by the need to provide required notifications	200	200	40000	8
‡8.1.3	Controllers are distracted in their response to *abnormal* situations by the need to continue to monitor and control unrelated, ongoing operations	2000	200	400000	2
‡8.1.4	Control room staff roles and responsibilities during *abnormal* situations are not well defined	2	200	400	53
8.2.1	Controllers are distracted from monitoring and controlling operations by the need to complete operations reports (e.g., operating sheets, production summaries, line status summaries)	2	10	20	97
8.2.2	Controllers end up completing work that is assigned to schedulers	2	10	20	97
8.2.3	Field personnel do not provide adequate or timely support to Controllers	2	200	400	53
8.2.4	Stressful relations with control room management distracts Controllers from monitoring and control operations	2	10	20	97
8.2.5	Stress resulting from productivity goals, incentives, or penalties distracts Controllers from monitoring and control operations	2	10	20	97
9.1.1	A Controller feels particularly drowsy or fatigued during early afternoon and/or early morning (e.g., around 2-5 am/pm)	10	200	2000	20
9.1.2	A Controller feels drowsy or tired throughout most of a shift	2	350	700	38
9.1.3	A Controller feels fatigued at the end of a shift	10	200	2000	20
9.2.1	Controllers get insufficient sleep because of transitions in shift schedules from day to night or night to day	10	200	2000	20
9.2.2	Controllers get insufficient sleep because of being called in to work a shift on short notice	2	200	400	53

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
9.2.3	Controllers get insufficient sleep because of overtime work	2	200	400	53
9.2.4	Controllers get insufficient sleep because of twelve hour shifts	2	10	20	97
9.2.5	Controllers get insufficient sleep because of ongoing understaffing	2	200	400	53
9.2.6	Controllers get insufficient sleep because of shift start times	2	10	20	97
9.3.1	Controllers experience reduced alertness during slow periods	2	105	210	82
9.3.2	Controllers experience difficulty regaining alertness to deal with a challenging situation following a slow period	0	200	0	116
9.4.1	Controllers report to work tired enough that they are concerned about their ability to run the pipeline*				
‡9.4.2	Controllers do not notify management when they report to work without adequate rest	2000	10	20000	12
10.1.1	Automation of control actions makes the Controller job more difficult	1	10	10	109
10.1.2	Too many steps are required to set up an automated sequence of control actions	1	10	10	109
10.1.3	Automated operation of some equipment conflicts or interferes with Controller actions	1	10	10	109
10.1.4	Controllers can forget to perform a manual control action because the initial steps are automated	0	200	0	116
10.1.5	Automation is not consistent across similar stations/locations	2	200	400	53
10.1.6	Controllers do not understand how automation works at a station/location	0	200	0	116
10.1.7	Controllers do not sufficiently trust the reliability of control action automation	2	105	210	82
10.1.8	There are some steps in an automated sequence that are not displayed by SCADA	0	10	0	116
10.1.9	There are specific control actions (e.g., line ups, line shutdown, and manifold flushing) that would benefit from automation	2	10	20	97
‡11.1.1	The location of break facilities keeps Controllers away from their console too long	200	105	21000	11
‡11.1.2	The location of break facilities keeps Controllers from taking appropriate brief breaks	200	10	2000	20
11.1.3	The lack of breaks during a shift makes it difficult to meet basic personal needs (i.e., food, bathroom, illness, etc)	10	105	1050	28
11.1.4	Controllers on break cannot be reached to address an immediate operational situation	1	500	500	45
11.2.1	Another Controller’s long break times puts an excessive burden on the relieving Controller	1	200	200	85

PF ID	Performance Factor	Prevalence Score	Risk Likelihood Score	Risk Level Score	Risk Level Ranking
11.2.2	Controller staffing is not adequate to cover for sudden problems (e.g., family emergencies, sudden serious illness, etc)	2	500	1000	29
11.2.3	Controller staffing is not adequate to allow for vacation, sick leave, and/or regularly scheduled days off	2	500	1000	29
11.2.4	Controllers work on their scheduled day off because of required participation in extra activities (e.g., special projects, meetings, training, etc.)	2	200	400	53
11.2.5	Controller staffing is not adequate to provide Controller assistance during busy *normal* operations	2	200	400	53
11.2.6	Controller staffing is not adequate to provide Controller assistance during *abnormal* situations	0	200	0	116

‡: These Performance Factors used a Yes/No response format during the trial application of the Controller Survey and were subsequently converted to a prevalence response format in the final version of the survey (with the exception of Performance Factors 7.1.2 and 9.4.3, which are not used to compute Prevalence or Risk Level scores. For the purposes of computing preliminary Prevalence scores from Yes/No Controller Survey item data, the following transformation based on the percentage of Controller Survey respondents who responded 'Yes' to an item was used: 0-5% Yes = 0 Prevalence score; 6-10% Yes = 1 Prevalence score; 11-15% Yes = 2 Prevalence score; 16-20% Yes = 10 Prevalence score; 21-25% Yes = 50 Prevalence score; 26-30% Yes = 200 Prevalence score; 31-40% Yes = 500 Prevalence score; >41% Yes = 1,000 Prevalence score.

* Note: Risk level score from 9.1.2.

APPENDIX G: OPERATIONAL REVIEW FEEDBACK FINDINGS

Operational reviews were conducted at a total of eight control centers and feedback surveys were provided by four separate operators. Among the operators who completed and submitted independent forms, the 1st-generation operational review procedures were applied to review 35 separate Performance Factors a total of 66 times. In these 66 applications, accident and incident reviews were completed 38 times, interviews were completed 61 times, structured observations were completed 13 times, and materials reviews were completed 27 times. The following table summarizes the operational review applications completed prior to providing the trial application feedback summarized in the subsequent tables.

The reader should note that there are variations in the wording and numbering between the Performance Factors that were used for the trial operational reviews and the final set of Performance Factors listed elsewhere throughout this report.

Summary of Performance Factors Investigated and Activities Conducted

Performance Factor Investigated	Number	Accident, Incident Review Completed	Interviews Completed	Observations Completed	Materials Review Completed
1.1.1 How often do you need to perform more than three steps to execute a control (e.g., valve, pumps, set point)?	2	0	2	1	0
1.1.2 How often do you perform routine activities (e.g., line start up, batch cutting, or manifold flushing) that are very complex?	4	4	3	0	1
1.1.3 How often are you required to perform manual calculations?	4	3	4	1	1
1.1.4 How often do you perform non-typical control actions (e.g., start/stop pump, open/close valve) that are different than control actions for similar equipment (e.g., pumps, valves, etc.) at the majority of locations?	1	0	1	0	0
1.1.5 How often do you perform an operation that has a very small margin for error?	4	3	4	0	3
1.2.1 How often do you have to perform two or more control operations (e.g., line switches) at the same time?	3	2	3	0	2
1.2.2 How often are you confronted with excessive telephone activity?	4	3	3	0	1
2.2.6 How often do you have to navigate between more than two SCADA displays to view related information?	1	1	1	0	1
4.1.1 How often do you get inaccurate SCADA data because of inaccurate field instruments (meters, gauges, etc)?	1	0	1	0	0
4.1.2 How often does a communication problem result in SCADA data becoming stale, out-of-date, or unavailable?	1	1	1	0	1

Performance Factor Investigated	Number	Accident, Incident Review Completed	Interviews Completed	Observations Completed	Materials Review Completed
5.1.5 How often do you use a procedure that does not meet the needs of both novice and experienced operators?	1	1	0	0	0
6.1.3 How often do you encounter a communications loss that results in a flood of alarms?	1	0	1	0	1
6.2.7 Alarms are not displayed in a consistent format, making their interpretation difficult	1	0	1	1	0
6.3.2 The alarm suppression/filtering system within the SCADA is not adequate	1	0	1	1	0
6.3.5 Can previously acknowledged alarms be accessed for review on the SCADA in two or less steps, screens, or keystrokes?	1	1	1	0	0
6.4.1 Is the number of nuisance alarms too high?	2	2	2	0	0
6.4.2 Are there too many unnecessary information alarms/notifications coming into the alarm screen that are not required for operations (e.g., “action started” or “action completed”)?	2	0	2	1	0
7.1.3 Have you been provided adequate training about hydraulics?	1	1	1	0	1
7.1.5 During initial training, were you rotated from one console before being comfortable with you ability to understand and operate it?	1	0	1	0	0
7.2.1 When a new pipeline or facility was last introduced on you console, were you provided adequate training before you had to start running it?	2	1	2	0	1
8.1.1 When dealing with *abnormal* situations, are you also required to respond to non-critical events (e.g., phone calls & nuisance alarms)?	4	4	4	1	2
8.1.3 When dealing with an *abnormal* situation, are you also required to monitor and control ongoing operations?	3	2	3	1	2
8.2.1 Controllers must respond to non-critical events (phone calls & nuisance alarms) during an *abnormal* event	1	0	1	1	0
8.2.2 How often do you have to complete work that is assigned to schedulers?	1	0	1	0	1
8.2.3 Controllers must monitor and control unrelated ongoing operations while dealing with an *abnormal* event	1	0	1	1	0
8.3.2 Controllers spend too much time preparing operations reports	1	0	1	1	0

Performance Factor Investigated	Number	Accident, Incident Review Completed	Interviews Completed	Observations Completed	Materials Review Completed
9.1.1 How often do you get insufficient sleep because of transitions in shift schedules from day to or night or to day?	1	1	1	0	1
9.1.4 How often do you get particularly drowsy or fatigued during early afternoon and/or morning (e.g., around 2-5 am/pm)?	1	1	1	0	1
9.3.1 Have you been provided training on sleep basics, personal alertness practices, and effective fatigue-reduction practices?	1	1	1	0	1
9.3.2 Are you encouraged to report when you are not feeling adequately rested?	4	4	4	0	2
11.1.1 Are break facilities in a convenient location?	3	0	3	3	0
11.1.3 How often do you have difficulty meeting basic personal needs (i.e., food, bathroom, illness, etc) because of the lack of breaks during a shift?	2	1	2	0	1
11.1.6 How often is Controller staffing not adequate to cover for sudden problems (e.g., family emergencies, sudden serious illness, etc)?	2	0	1	0	1
11.1.7 How often is Controller staffing not adequate to allow for you vacation, sick leave, and regularly scheduled days off?	2	0	1	0	2
11.1.10 How often is Controller staffing not adequate to provide you with assistance during *abnormal* situations?	1	1	1	0	0
Totals: 35	**66**	**38**	**61**	**13**	**27**

FEEDBACK FORM 1: ON-SITE OPERATIONAL REVIEW GUIDANCE DOCUMENT AND CONTROLLER SURVEY ANALYSIS REPORT

1.1. Does the *Guidance Document* provide a clear overview of the on-site operational review process?

Yes: 1.5 **Somewhat: 2** **No: 0.5**	**If Yes, please identify what was most useful:** **Co. A:** Procedure description clear, Attachment 3 was the most useful part of the document with it's suggested topics to cover for each PF **Co. B:** The step by step explanation.
	If Somewhat or No, please identify needed improvements: **Co. A:** While the procedures were clear, it wasn't immediately apparent what the purpose of each document/step was. This made it difficult to determine which steps were absolutely necessary and how they could be addressed alternatively. **Co. C:** • Simplify instructions and process • Inconsistency between instructional vs. actual worksheets Under step 1 scoping work sheet title is inconsistent. (Doesn't match) • Forms for capturing data, the form titles were misleading • Interview form has no way to capture interviewee's responses. **Co. D:** The explanation of requirements to complete each section was helpful to compile and complete each step of the process. However, the guidance document had to be repeatedly referred too. Causing the process to be quite lengthy**.**

1.2 Does the *Guidance Document* provide a clear explanation of the Controller Survey Report analyses?

Yes: **Somewhat: 3** **No: 1**	**If Yes, please identify what was most useful:**
	If Somewhat or No, please identify needed improvements: **Co. A:** It was useful information that may have been more appropriate in an appendix. What mattered most was the ranking. **Co. B:** Too much detail in the explanation obscures the explanation. It isn't necessary to include the statistical tests explanations in detail. **Co. C:** • The document was geared towards fixing problems that are not considered problems in the industry • It would be beneficial if the document guided towards evaluating current standards and practices **Co. D:** Although the guidance provided a clear explanation the report analysis charts were not always clear**.**

1.3 Are the *Risk Level* procedures appropriate for the objectives of the operational review?

<table>
<tr><td rowspan="2">Yes:

Somewhat:

No: 4</td><td>If Yes, please identify what was most useful:</td></tr>
<tr><td>If Somewhat or No, please identify needed improvements:
Co. A: This was the area that interviewee's struggled the most in understanding. With a risk practitioner performing the interviews, they were able to be guided through scenarios leading to undesirable events, but it was the most complex part of the process. It may be difficult to complete this portion of the review without a qualified risk practitioner.
Co. B: If we're going to describe and assess risk, there needs to be more specific categories and the risk consequence definitions need to be more realistic. The probability of occurrence has too long time spans for occurrences. Most risk likelihoods are going to be low and very low, since the likelihood of some type of abnormal situation being caused by most of the factors is very, very low.
Co. C:
• Parameters were difficult to apply to industry
• Parameters caused user to attempt to pigeon hole risk levels when not applicable
• Step 1 says "potential" operational risk, step 3 and step 4 says "nature" of operational risk.
Co. D: Separate out the parameters for the risk level, broaden the likelihood and use terminology closely associated with industry.</td></tr>
</table>

1.4 Does the *Guidance Document* provide information about Individual Performance Factors and Human Factors Topics (Attachment 3) useful in preparing for and conducting operational reviews?

<table>
<tr><td rowspan="2">Yes: 2

Somewhat: 2

No:</td><td>If Yes, please identify what was most useful:
Co. A: This was the most useful part of the document – notably the proposed/suggested topics.
Co. B: The categories make sense, the topics fit for the most part, and the performance factors fit the categories for the most part.</td></tr>
<tr><td>If Somewhat or No, please identify needed improvements:
Co. C:
• More detail would be helpful
• Include examples on actual worksheets
Co. D: Minimal use for Controller interviews only</td></tr>
</table>

1.5 Do the summary charts and tables in the *Controller Survey Analysis Report* provide information useful in identifying and prioritizing areas of potential operational risk?

<table>
<tr><td rowspan="2">Yes: 1

Somewhat: 1

No: 2</td><td>If Yes, please identify what was most useful:
Co. B: Charts and tables make it easy to see what the items with "highest" ratings are.</td></tr>
<tr><td>If Somewhat or No, please identify needed improvements:
Co. A: Too much paper caused the entire thing to be flipped through and ignored. The ranking was the most important part of this. However, once the PF's were selected for inclusion in the OR's, a copy of the relevant survey questions was included at interview to help the interviewee understand the scope of the interview and some feedback provided by those who completed the survey.
Co. C: Good information yet not applicable in Co. C analysis
Co. D: We did not use it to identify for prioritizing however, we did use it for the purpose of identifying the related human factors.</td></tr>
</table>

1.6 Do the individual Performance Factor charts and statistical tests in the *Controller Survey Analysis Report* provide information useful in preparing for and conducting operational reviews?

Yes: 2 **Somewhat: 1** **No: 1**	**If Yes, please identify what was most useful:** **Co. D:** We were able to see the frequency of our Controller responses compared to the rest of industry
	If Somewhat or No, please identify needed improvements: **Co. A:** See above – not needed **Co. B:** I didn't find the statistical tests and findings useful in preparing for the review. **Co. C:** Helped in identifying when confusion may have played a part in responses

1.7 Do the Controller Comments in the *Controller Survey Analysis Report* provide information useful in preparing for and conducting operational reviews?

Yes: 3 **Somewhat:** **No: 1**	**If Yes, please identify what was most useful:** **Co. A:** Combined with the suggested topics from Attachment 3, they formed the basis of the prepared interview questions. All the interviewee's were impressed by the appropriateness and correctness of the prepared questions; particularly from someone not highly familiar with control room operations. **Co. C**: Helped in understanding the Controller's interpretation of questions **Co. D:** The degree of positive or negative responses to the survey questions was insightful to management.
	If Somewhat or No, please identify needed improvements: **Co. B:** Most of the comments appeared unrelated or very loosely related to the factors.

FEEDBACK FORM 2: OPERATIONAL REVIEW APPLICATION FEEDBACK

2.1 Was the *Step 1 Scoping Worksheet* useful in preparing and documenting the plan for conducting operational reviews?

Yes: 2 **Somewhat: 2** **No:**	**If Yes, please identify what was most useful:** **Co. B:** The worksheet identified the areas that we were to review in this operational review. **Co. C**: Made the process consistent
	If Somewhat or No, please identify needed improvements: **Co. A:** It helped to plan whether observations, interviews, record reviews, and/or incident reviews were to be employed. However, it wasn't used or referenced after wards. **Co. D:** We needed a clear understanding on how the related performance factors were going to be used in the overall process. However, the process of identifying the potential related factors and constraints and the potential operational risk were helpful in analyzing the human factor.

2.2 In conducting *Step 2 Accident, Incident, and Near-Incident Report Review*, were you able to identify a relevant and manageable set of company reports?

Yes: 1 **Somewhat: 2** **No: 1** **NA:**	**If Yes, please provide suggestions regarding appropriate selection strategies:** **Co. C**: Co. C has an ongoing program to identify and address accident, incident and near-incident report review (RLG violations)
	If Somewhat or No, please describe the challenges you encountered: **Co. A:** Reviews were proposed but not completed. **Co. B:** Since a number of these factors have not been previously included in incident analyses, no reports had information relevant to most of the performance factors. While it may be worthwhile, for research's sake, to include all these human factors areas, I wonder about the benefit relative to the time involved. I don't know how much cognitive interviewing would be necessary to get useful information from incidents caused by human error. **Co. D:** We weren't always able to tie a human factor to a documented incident and had to rely solely on interviews.

2.3 Was the *Step 2 Accident, Incident, and Near-Incident Report Summary Worksheet* useful in documenting your incident review findings?

Yes: 1 **Somewhat: 2** **No:** **NA: 1**	**If Yes, please identify what was most useful:** **Co. D:** It helped us arrive at the potential mitigations that would be helpful in taking action to the potential risk.
	If Somewhat or No, please identify needed improvements: **Co. B:** The "related general factors and constraints" was not too useful. We should develop additional guidance on nature of operational risk and add those items to the forms.

2.4 In preparing for *Step 3 Interviews*, were you able to identify appropriate interview topics?

Yes: 3 **Somewhat:** **No:** **NA:**	**If Yes, please provide suggestions regarding appropriate interview strategies:** **Co. A:** The form was confusing. It could have been limited to a section pre-populated with relevant comments from the survey and prepared questions for the interview. **Co. B:** Help people feel comfortable; use open-ended questions; listen carefully; repeat back what you heard to ensure you received the same message that was delivered. **Co. C:** • Copied data from existing Co. C forms • Revise forms to be more user friendly **Co. D:** Framework of human factors and potential interview topics listed in the operational document was adequate but many of the interview topics were spawned from the Controllers because of the openness and non-threatening environment of the interview
	If Somewhat or No, please describe the challenges you encountered:

2.5 Was the *Step 3 Interview Worksheet* useful in documenting your interview findings?

Yes: 1 **Somewhat: 2** **No: 1** **NA:**	**If Yes, please identify what was most useful:** **Co. D:** The form was useful to give us a format to follow for each interview.
	If Somewhat or No, please identify needed improvements: **Co. A:** All prepared questions and responses were put in the same area that didn't seem to be the right one. The form did not really guide or assist in performing the interview. **Co. B: :** It is difficult for the Controller to decide on working condition frequency. Part of that is due to terms like "excessive, complex, etc." that are used in some of the performance factors. **Co. C:** No space to capture responses or to document questions

2.6 In preparing for *Step 3 Observations*, were you able to identify appropriate observation activities?

Yes: 1 **Somewhat: 2** **No:** **NA: 1**	**If Yes, please provide suggestions regarding appropriate observation activities:** **Co. D:** Observe the Controller during various times of his or her shift performing different tasks.
	If Somewhat or No, please describe the challenges you encountered: **Co. A:** Topics discussed in Attachment 3 were most useful. However, the planned observations did not occur in the planned manner. **Co. B:** With the 15 factors I reviewed, most of them did not have observable activities that could be done without spending much time waiting for an occurrence.

2.7 Was the *Step 3 Observation Worksheet* useful in documenting your observation findings?

Yes: 2 **Somewhat: 1** **No:** **NA: 1**	**If Yes, please identify what was most useful:** **Co. B:** This was the most useful sheet, because the sections had clear meanings. **Co. D:** The format of the observation worksheet allowed us to develop relevant protocol questions.
	If Somewhat or No, please identify needed improvements: **Co. A:** Since the findings varied from the plan, many of the topics became moot. Filling out the form was of little value.

2.8 In preparing for *Step 3 Materials Review* activities, were you able to identify appropriate review topics?

Yes: 2 **Somewhat: 1** **No: 1** **NA:**	**If Yes, please provide suggestions regarding appropriate materials review activities:** **Co. A:** ….Attachment 3…… **Co. D:** Work schedules, training history records, event logs, alarm logs, shift change documents, however, review topics will vary from control center based on the human factor being reviewed.
	If Somewhat or No, please describe the challenges you encountered: **Co. B:** There were no materials for most of these factors. That doesn't mean any need to be developed **Co. C:** Form was too vague.

2.9 Was the *Step 3 Materials Review Worksheet* useful in documenting the results of reviews?

Yes: 3 **Somewhat: 1** **No:** **NA:**	**If Yes, please identify what was most useful:** **Co. A:** It was easier to use a 'form' for documenting things that are more concrete. **Co. B:** Nothing in particular was most useful. This sheet was clear and straightforward. **Co. D:** The format of the materials review worksheet allowed us to document relevant Controller comments and compare to the findings.
	If Somewhat or No, please identify needed improvements: **Co. C:** No place for mitigations

2.10 In completing the *Step 4 Summary Sheet*, were you able to describe *Related General Factors and Constraints* that were relevant to your Operational Review?

Yes: 2 **Somewhat: 2** **No:**	**If Somewhat or No, please summarize the challenges you encountered:** **Co. A:** This section was used more as a summary of the results. Any significant factors or constraints were dealt with during the planning or execution phases. **Co. B:** I could describe some, although I didn't think it should be necessary. We need to look at specifics, not generalities.

2.11 In completing the *Step 4 Summary Sheet*, were you able to describe *Specific Working Conditions* that were relevant to your Operational Review?

Yes: 2 **Somewhat: 2** **No:**	**If Somewhat or No, please summarize the challenges you encountered:** **Co. A:** Most did not need to describe these conditions so this was used to highlight key issues raised during the previous tasks. **Co. D:** In regards to the incident report there were no challenges but during the interview process coaching was used to identify what possible working conditions exist.

2.12 In completing the *Step 4 Summary Sheet*, were you able to describe the *Nature of Operational Risk* in a way that was relevant to your Operational Review?

Yes: 2 **Somewhat: 2** **No:**	**If Somewhat or No, please summarize the challenges you encountered:** **Co. A:** This turned out to be a summary of findings from the interview. There will still need to be a 1-page summary put together to highlight the most significant issues and measures that can be employed. It does not seem reasonable to expect a risk manager to go through all these details. **Co. B:** Same response as question about nature of operational risk on other form. I think the summary sheet was repetitious and unnecessary. Whoever compiles the results of the review could do a summary.

2.13 In completing the *Step 4 Summary Sheet*, were you able to identify the *Level of Risk* in way that was relevant to your Operational Review?

Yes: 1 **Somewhat: 1** **No: 2**	**If Somewhat or No, please summarize the challenges you encountered:** **Co. A:** Yes – in terms of the risk scale provided in the report. However this does not correlate directly to the risk scale used internally. **Co. B:** Same response as question on other form. Risk Consequence and Risk Likelihood are not based on realistic factors. **Co. D:** The level of risk chart needs to be separated out into three categories financial impact, personnel and environmental. The categories and definitions should be agreed upon by the industry team.

2.14 In completing the *Step 4 Summary Sheet*, were you able to describe *Potential Mitigations* that were relevant to your Operational Review?

Yes: 3 **Somewhat: 1** **No:**	**If Somewhat or No, please summarize the challenges you encountered:** **Co. A:** Again, this is mostly a summary of what was covered in the interview. Since this includes a small subset of the Controllers, and it was clear that there are differing opinions and perspectives of the interviewees, this small subset may not provide an accurate representation of the risk or value of the proposed mitigative measures. **Co. B:** I could describe potential mitigations, but it would be more relevant if the risks assessment was more relevant.