Alaska Maritime Human Factors Needs Assessment

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Executive Summary

This report presents the results of an assessment of research needs in human factors for the Alaska maritime system. The purpose of the study is to provide the Regional Citizens Advisory Councils with information to guide the allocation of resources to human factors research topics.

The needs assessment was carried out by means of a structured interview approach. During the spring and summer of 1994, 40 members of the Alaska maritime community were interviewed concerning human factors issues. The interviewees comprised ship masters and crew, U.S. Coast Guard, state regulators, shipping company executives, response and escort vessel personnel, pilots, and shoreside personnel. The results of the interviews were content analyzed to identify the specific human factors issues and research topic. The results included identification of nine human factors topics, falling into two broad categories, as shown below:

Individual Human Operator Focus	Organization/System Focus
• Personnel Skills, Resources and Certification • Fatigue • Automation and Technology • Training	• Changes in the Maritime Industry • Individual and Organizational Behavior • Policies and Regulation • Oil Spill Response • Facilities and Inland Marine Transport

For each of the human factors topic areas, background information is provided, along with suggested research methods, timelines for accomplishment, and expected results. A number of these topic areas are the subject of planned or on-going research at the federal level. These efforts are described further in the appendices to the report. It is recommended that the RCACs leverage Alaska-based human factors research efforts by complementing and coordinating with federal-based efforts; the experience base offered by existing and on-going research projects will be valuable in amplifying human factors research that is specific to Alaska.

1. Introduction

Human factors engineering is concerned with developing safe and effective human-machine interfaces in systems, including ship's bridges, cargo operations, and piloting procedures. Evaluation of a number of transportation accidents, including maritime, indicate that human error is the root cause in at least 80% of the cases. Consequently, human factors are critical aspects of accident prevention programs, and are receiving increased attention at both state and federal levels.

The U.S. Coast Guard recently published a plan for human factors research in maritime safety. Similarly, the state of Washington has undertaken human factors work. There is interest in other port and shipping states, as well. The principal goal of human factors research is the enhancement of safety and the prevention of environmental and human casualties. Examples of such enhancements include user-friendly electronic chart systems to guide navigation, alternative watch standing schedules to reduce crew fatigue, and enhanced technology to reduce crew workload, such as automated docking systems..

The purpose of this report is to identify a set of human factors research topics that will guide the Regional Citizens Advisory Councils (RCACs) as they focus financial resources for spill prevention research. A parallel goal is to focus on human factors problems that may be unique to the Alaska shipping trade. This report makes two primary assumptions that are fundamental to the conduct of the needs assessment:

- *First, it is assumed that resources will be allocated to the study of human factors, particularly maritime human factors, in the state of Alaska.* Thus, the question the research team was faced with was not "should resources be directed toward the study of maritime human factors in Alaska?" but rather, "on which high priority topics should resources be focused on?"

- *Second, this report is intended to provide a consolidated reflection of the opinions of the participants in the study (i.e., members of the Cook Inlet and Prince William Sound maritime community.)* Readers should not necessarily assume that the opinions consolidated here reflect the research priorities of the RCAC's or of any of the interview participants or the report authors. Since resources are expected to be focused on maritime human factors in Alaska, the study team consequently queried members of the maritime community--operators, regulators, management and technicians--about what topics were of interest for study.

2. Background

Because of the high level of interest in human factors engineering in the maritime community, it is worth providing some brief background information to establish a context for our findings. There are three background points that need to be made:

- Human factors research is domain-specific
- Solutions to human factors research problems are most often of a general nature, and
- Human factors research can be quantitative or qualitative

The first point concerns conducting human factors research in the maritime domain. There is an extensive body of research conducted for aviation and nuclear power applications, some of which is applicable to shipping. However, specific solutions to problems such as fatigue from unconventional work schedules, or team performance training for bridge operations, need to be developed in the maritime context. Direct application of research from other operational areas is usually inappropriate.

The second point addresses the nature of solutions to human factors problems. While human factors research needs to be specific to the maritime domain, the solutions that are generated will be general across geographic boundaries. For example, the best way to train a person to use an ECDIS will be the same for oil tankers or freight ships. Similarly, watch schedules that reduce fatigue are likely to provide benefits throughout the industry. In some special cases it may be possible to focus on regionally-specific issues, such as chronic foul weather, complex port organizations, and extensive periods of daylight. When possible, our proposed research plans address Alaska-specific issues.

The third point addresses the nature of human factors research methods, which can be of a quantitative or qualitative nature. When basic model building (i.e., description of a problem) is required, qualitative research is usually required, such as case studies. For purposes of determining the impact of a proposed operational, engineering or regulatory change, quantitative research would be appropriate. The research plans described below use both approaches, as required by the topic area.

The following sections provide descriptions of the study methods and results..

3. Methods

The goal of this report is to identify a set of maritime human factors research projects that will prove useful to the Regional Citizens Advisory Councils (RCACs), as well as state, federal, and industry parties in assessing Alaskan maritime human factors interests. This report represents the consensus of the maritime community of Prince William Sound and Cook Inlet, as reflected in a series of interviews with industry, state, and federal participants conducted during the spring and summer of 1994. The numbers and types of individuals interviewed during the study are listed in Table 1.

TABLE 1. NUMBERS AND TYPES OF STUDY RESPONDENTS

Tanker/Freight ship masters	6
Chief Engineers	3
Chief mates	2
Other deck/engine crew	3
USCG Valdez	4
USCG Anchorage	4
ADEC	4
Response/escort vessel personnel	5
Shipping Company management	3
Pilots	2
Shipping/response vessel shoreside personnel	4
Total	40

The study adopted a structured interview approach, concentrating on topics of interest to parties in the maritime community. Attention was paid to balancing the numbers and types of interview participants to provide an appropriate mix and number of participants, within the limits of the project budget. In addition to local regulators, management, operators, and technicians, three industry executives were interviewed.

Very few specific research topics were suggested by the interviewees. Most individuals, and operations experts in particular, are adept at describing a situation, rather than at articulating research agendas to address the observations made. Thus, the study methodology focused on eliciting observations, opinions, descriptions, and scenarios. Interviewees were also asked if they could articulate specific research topics of interest; those that were articulated have been included in this report. However, the majority of the research topics described here were induced from the interview responses, rather than articulated directly by the study participants. The study methodology anticipated such results, and accounted for the nature of interview descriptions by use of a combination of *knowledge acquisition* techniques (to elicit meaningful responses from participants) and *content analysis* techniques (to insure that the responses obtained from the participants were adequately and accurately represented by this report summary).

Two interviewees indicated that this human factors needs assessment was an effort in search of a problem to solve, i.e., that few human factors topics worth researching could be identified. The same interviewees suggested that assessing the impact of reduced daylight on Alaska maritime operations is probably worthwhile.

The following sets of questions comprised the general interview protocol during the interviews:

- descriptions of interviewee backgrounds, history, experience and longevity in the Alaska trade,
- descriptions of particular roles, responsibilities, and operations in the Alaska trade,
- descriptions of personnel, training, certification and recertification, morale and motivation, fatigue, work and watch schedules,
- opinions of organizational "best practices" and "lessons learned,"
- changes observed in operations, training, personnel, watch schedules, requirements, and regulation in the past 5, 10 and 15 years, and
- differences between seasons, trades, routes, and operating conditions (wind, weather, ice, etc.), and
- finally, interviewee recommendations for research topics.

Following the focused interviews, the study team performed a content analysis of the consolidated results, and prepared this report. Readers should note that not all human factors topics listed are of interest to all segments of the maritime community (i.e., some topics are of interest to shipping companies, and of little interest to terminal operators); at the same time, some topics span a mix of interests and sectors in the maritime community. In all cases, interviews were conducted on a non-attribution basis, and study participants were told that they would be able to review a draft of the resulting report in order to provide feedback on its contents. Study participants were told of the timelines for the report in order to support short feedback and turnaround cycles.

4. Human Factors Topics and Project Descriptions

Eight broad topics of interest were generated by the interviews with the study participants. These broad human factors topics include:

- Changes in the Maritime Industry
- Policies and regulations
- Oil spill response
- Individual and Organizational Behavior
- Facilities and Inland Marine Transport
- Automation and Technology
- Training
- Fatigue
- Personnel skills, Resources, and Certification

These general project areas encompass a number of sub-topics, which will be discussed in more detail in the following pages. It is noteworthy that the topics of fatigue and automation and technology were identified as priority research issues across all transportation modes at a recent intermodal transport conference.

Descriptions of the research projects delineated above follow in this section. Each of these topic areas is described with brief descriptions of:

- background (if applicable)
- description of research topic area;
- example methodology or procedure to address research problem;
- timeline required for topic; and
- expected results of the topic area.

In cases where there are related research efforts or extensive programs have been proposed but not yet implemented, further detail is provided in appendices to the report.

4.1 Changes in the Maritime Industry

Many interviewees expressed an interest in an analysis of changes in the national, international, and Alaska maritime system. Interviewees expressed concern at the rapidity and direction of recent changes in the industry, particularly the number and type of new regulations and requirements. In several instances, interviewees noted with dismay the "brain drain" occurring in the industry as bright, young, industry-savvy individuals look to places other than the maritime industry for employment. In addition to surveying and documenting these changes, interviewees suggested investigations of the following topics:

- identification of the impact of fluidity and fluctuation in the industry on individual morale and motivation,
- articulation of new skills requirements, and identification of best achievable paths for acquiring those skills (see Topic 4.4, Personnel Skills and Resources, and 4.8, Training)
- analysis of the impact of post-OPA-90 changes in the Alaska maritime system,
- analysis of migration patterns of big ship people to smaller boats, and an assessment of the impact of such migration on individual and organizational expectations, performance, individual values and organizational cultures, decision-making styles, training required, etc.,
- impacts of such changes on requirements for crew continuity, and
- identification of interventions designed to prevent or mitigate long-term detrimental effects of changes in the maritime industry on the Alaska maritime system.

Suggested Research Methodology

Case analyses, cost-benefit analyses, skills and task analyses, and social forces modeling might be appropriate research methodologies. A comparison with earlier descriptions of the Alaskan maritime system, national, and international maritime industry might provide a useful context within which to appreciate the analysis conducted under this topic area.

Timelines

A preliminary analysis of this topic area could be performed within a 12 month time frame; a longitudinal assessment (an assessment of changes in an environment or system over time (i.e., 10, 20 or 30 years) might provide additional interesting results.

Expected Results

This primarily qualitative research project could be expected to provide a context for human factors in Alaska. Such a research project could:

- provide a snapshot of the Alaska maritime system in comparison with national and international systems,
- identify trends
- assess the impact of those trends

- articulate "best practices" and "lessons learned" and desired enhancements to the Alaska maritime system.

4.2 *Individual and Organizational Behavior*

Interviewees often suggested a variety of individual and organizational behavior topics when queried. Mentioned most often during the interviews were the necessity for organizational and individual communication, effective decision-making, information sharing, and a "system-wide" appreciation of the impact of small changes on the safety and effectiveness of the entire maritime system.

Several interviewees described incidents where increased communication, effective decision making, and a system-wide appreciation of players, their roles and responsibilities would enhance working in the system. Each of these similar stories was usually followed with two assertions: (1) that there was nothing unique to the Alaskan trade inherent in these descriptions, and (2) that addressing these topics is something that many individuals and groups have been working on for a long period of time. In fact, there is little about the individual and organizational behaviors described (i.e., decision making, communication information sharing, etc.), that appears peculiar to Alaska. Further, some current related research, with a more global approach (i.e., national and international) is being supported by the National Science Foundation (NSF) and the Federal Aviation Administration.

Thus, if such a research topic were to be pursued, it should be conducted within a broader context, with Alaska resources focused on Alaska-specific enhancements to communications patterns, decision making, etc. Issues appropriate for an Alaska research program could include:

- identification of the roles, responsibilities, interfaces, required interactions, infrastructure, and communications of each of the elements of the Alaska maritime system (i.e., Coast Guard, shipowners, ship operators, shipping management, terminal and facilities operators, terminal and facilities management, industry consortia, state and regional regulatory interests, environmental interests, native interests, response and escort vessels, pilots, the media, and the interested public, etc.). This identification should include a current snapshot of these elements (what exists) and a vision of what the desired elements should look like for a safe and effective Alaska maritime system,
- articulation of methods to enhance the development of trust and communications in the Alaska maritime system, and

- assessment of the adequacy of the information and technology infrastructure supporting individuals and organizations in the Alaska maritime system (i.e., should the federal regulatory agency have a water vehicle to assist in carrying out its duties? does the vessel traffic services (VTS) have adequate (physical and informational) visibility in order to safely and effectively carry out its duties?

Suggested Research Methodology

This research topic could be pursued by a series of model or framework identification, development, and evaluation activities. Close interaction with and participation of members of the Alaska maritime community is essential for the development of a credible and useful framework. This research effort should be pursued in parallel with other federal and Executive branch research efforts (i.e., U.S. Coast Guard and National Research Council, Marine Board). Local efforts addressing smaller issues could be addressed on a smaller scale.

Timelines

This research topic could be pursued over the course of a 12 to 18 month period.

Expected Results

This qualitative research project could be expected to (1) describe Alaska-specific individual and organizational behaviors, (2) describe methods to enhance the safety and reliability of the Alaska maritime system, (3) assess the adequacy of the information and technology infrastructure present in the Alaska maritime system, and (4) recommend enhancements to the system if desirable.

4.3 Policies and Regulation

Many interviewees suggested assessing the impact of changes in the maritime industry, in organizations, on vessels and in facilities, and in regulatory organizations; most participants indicated that assessments of changes were needed in two areas: overall system safety and system effectiveness. In most cases, the topics were articulated in this way: "with increasing changes in regulations, in regulatory bodies, and requirements, does the total impact of such changes make the system any safer? Also, does the resulting system "make sense?"

Research topics which address these concerns could include:

- a systems and risk analysis of the impact of different regulations on the safety and effectiveness of the Alaska maritime system,
- a cost-benefit and comparative analysis of pre-OPA-90 and post-OPA-90 regulations and requirements with respect to the safety and effectiveness of the Alaska maritime system,
- an identification of the results and incompatibilities (if any) of OPA-90 and follow-on requirements and regulations on the safety and effectiveness of the Alaska maritime system,
- an articulation of any enhancements needed to address discontinuities in the patchwork quilt of regulations and requirements, (i.e., ways to reduce incompatibilities, conflicting requirements for the same goal, etc.,), and
- the development of "best achievable practices and protections" in Alaska maritime operations and affairs, *developed in concert with, and with the consensus of the Alaskan maritime community.*

The five research topics listed above are, in fact, interrelated and are best considered together, particularly as assessments of the interactions between the systems and analyses listed above may yield interesting and important findings. These five research topics could be subsumed under more global assessments, such as:

- a systems analysis of the interactions between the different elements which comprise the Alaska maritime system (state, regional, federal, native, and international),
- an articulation of how these interacting elements should proceed, regulate, legislate, and cooperate in order to enhance the safety and effectiveness of the Alaska maritime system.

Caution is advised before proceeding too rapidly in this topic area, however. A systems of risk analysis of the Alaska maritime (human factors) system, by definition, should be focused on the state of Alaska and its member constituents. Readers should be advised, however, that a set of preliminary analyses at the federal level should precede an Alaska effort (i.e., funded by the Coast Guard, National Science Foundation, or Department of Transportation). Alaska resources could thus be focused on the Alaska-specific elements of the topic area, after the more global national assessments were conducted. Conducting the Alaskan research in the context of a broader research agenda limits the possibilities of suboptimization (i.e., solving a problem at a local level to the detriment of the overall system).

Such a broad research agenda is being articulated at the national level, with support from the U.S. Coast Guard, a number of maritime states, regional organizations, and the Maritime industry. For example, there is currently a research effort being developed by the Volpe National Transportation Systems Center to conduct a cost-benefit analysis of various human factors elements of OPA-90. Alaska-based research could be defined on the basis of results from this on-going work.

Suggested Research Methodology

This topic area might be pursued as a framework development type of task. Interviews, questionnaires, observation, and knowledge acquisition techniques could be combined with systems and risk analyses of the Alaska maritime system. Risk analyses conducted should incorporate quantitative as well as qualitative assessments of risk in the Alaskan maritime human factors domain, and should incorporate the expert domain knowledge of the maritime community.

Timelines

This project could (should) be planned and undertaken in parallel with the previously mentioned federal, state and industry efforts. The Alaska-specific portions of this effort could be conducted over a two year period, in consultation with the other related research.

Expected Results

The results of these quantitative and qualitative research projects could be a framework outlining the essential elements, interactions, and workings of a safe and effective maritime system, as well as the impact of changes in policies and regulations on that system. A national and international framework could be developed at the national level; a parallel effort outlining the essential elements of a safe and effective Alaska maritime system, which encompasses technical, human, organizational, and environmental elements, could be the result of the Alaska effort. These research efforts should be cast in terms of defining the Alaska-specific contributions/understandings of the larger overall projects, rather than defining all pieces of the framework.

4.4 *Personnel Skills, Resources, and Certification*

Many interviewees expressed interest in identifying changes occurring in the maritime industry (Topic 4.1), as well as in identifying the impact of these changes on personnel skills and resources required, and the corresponding certification requirements. Interviewees expressed interest in the following topics:

- job skills and tasks analyses of shipboard and shoreside positions (to address the following question: with the multitude of changes occurring in the maritime industry, are the correct resources deployed aboard vessels and shoreside? What skills and functions need to be performed today that are new, and what personnel resources are required to perform those functions (i.e., how should manning scales reflect new requirements?)
- from the mariner's perspective, what operational and technical support is needed by mariners in order to enhance the safety, effectiveness, and efficiency of oil transport operations?
- given changes in the national and international maritime systems, how should individuals be certified for performance in the oil transportation system and in the Alaska maritime system?

Suggested Research Methodology

A mix of research methods is suggested for this topic area: job, skills, and task analyses for shipboard and shoreside personnel; manning studies and empirical experiments; personnel questionnaires and surveys; and training system investigations. Several U.S. Coast Guard sponsored research efforts are on-going in this area; further details on these programs is provided in Appendix A.

Timelines

This project could be completed during a 12 month period, in many cases as an adjunct to on-going projects being carried out by federal organizations investigating personnel skills and resources for shipboard and shoreside operations.

Expected Results

The results of this primarily qualitative research project could be expected to provide (1) identification of skill and task requirements for shipboard and shoreside positions, (2) an identification of new skills and functions, (3) identification of required and revised personnel resources to address the needed skills and functions, (4) assessments of operational and technical support required by mariners in order to enhance the safety, effectiveness, and efficiency of oil transport operations, and (5) requirements for certification.

4.5 Oil Spill Response

A few interviewees suggested that human factors in oil spill response might be an appropriate study area. Specifically, the following topics were suggested:

- a cost/benefit assessment of using oil in spill response drills (instead of oranges, buoys, or hula hoops),
- an analysis of the contribution of aviation resources to spill exercises and responses (i.e., analysis of the communication, decision making, information sharing patterns required for effective spill response),
- development of "reasonable" oil spill response expectations (response times, crew rest periods, crew effectiveness, expected recovery, etc.) especially in adverse weather conditions, and with a variety of activities required of response personnel. Such an assessment would include study of how crew effectiveness and responsiveness can be enhanced for cold and adverse weather conditions, and,
- development of user-friendly and effective information and decision support systems to assist spill responders during spill response drills, as well as during actual incidents.

Timelines

These projects could be completed within a 12 - 24 month time period.

Expected Results

This quantitative and qualitative research could be undertaken in order to understand more fully the nature of spill response activities and requirements in Alaska. In contrast to several other topics mentioned thus, far, interviewees felt that this topic had significant Alaska-specific knowledge and practices.

4.6 Fatigue

Fatigue has been implicated in numerous types of transportation accidents. Fatigue and duty period guidelines and regulations are used by virtually all transportation modes, and are most stringent in the case of commercial aircraft. OPA -90 established a maximum duty period of 15 hours per 24 or 36 per 72, except in the case of emergencies. There is consensus among industry personnel that this rule has eased the workload during cargo periods by adding a loading mate, or making the chief mate job a day work position. A number of fatigue-related topics were suggested:

- examining the impacts of seasonal variations in daylight and multiple time zone crossings on work patterns and adaptations of circadian rhythms,
- investigating whether effective sleep/rest/work cycles for Alaska maritime operations can be defined,
- assessing whether a series of strategic naps combined with one longer sleep period can provide effective sleep/rest/work cycles for Alaska maritime workers,
- investigating potential alternative watchstanding schedules (daywork, shift work, close watch; and matching watchstanding schedules to skills/tasks), and
- examining the impacts of sleep disruption on work patterns and effectiveness.

There has been a substantial amount of work on the problem of fatigue and adaptation in conventional shift schedules, where the problems usually relate to issues of biological rhythm adaptation, and the rotation of shifts. Much less is known about unconventional shifts, such as those worked by ship crews. Research by British scientists suggests that conventional ship work schedules, such as 4 hours on - 8 hours off - 4 hours on, are associated with poor sleep quality and duration. Preliminary tests of alternative watch standing schedules indicates that these problems might be alleviated if a longer rest period were provided. In aviation, it has been found that appropriate scheduling of brief rest periods during longer work hours has a beneficial impact on pilot performance.

Suggested Research Methodology

A research approach to this problem involves establishing baseline measures of fatigue, sleep quality and duration, and work performed. Developing alternatives and evaluating improvement depends on having these types of data. The basic approach would entail obtaining rating data and sleep diary information from crews in the TAPS trade. Similarly, the jobs carried out during the various watches would need to be described in detail in order to design alternative watch schedules to accommodate the work that needs to be performed. Given this baseline data, the research team would design alternative watch standing schedules that would have the objective of providing mariners with longer rest periods between work activities. Implementation and testing of these schedules would be accomplished in collaboration with members of the TAPS fleet. Appropriate data would be collected to evaluate the impact of the new watch schedules.

The U.S. Coast Guard is planning to conduct a study of crew adaptation and fatigue aboard commercial vessels in 1995. Further details on the proposed methodology is contained in Appendix B.

Timeline

The timeline for this project would be three years. This is because it is necessary to collect baseline data over the span of all seasons to account for sleep disruptions due to variations in weather and light. The second year would be spent developing the alternative watchstanding schedules and implementing them within the fleet. The latter part of the second and third year would be spent gathering evaluation data to assess the costs and benefits of alternative work schedules.

Expected Results

The principal result of this work will be guidelines for alternative watch standing and work schedules for mariners. These schedules would reflect the demanding circumstances of Alaska shipping, such as weather and repeated time zone crossings, and will include adaptations of findings in aviation, such as scheduled napping.

4.7 Automation and Technology

Considerable concern about new technology was expressed among the intervieweess, particularly in terms of its utility and potential to create more work. This issue becomes increasingly important as shipping companies incorporate advanced automation into newly constructed ships or ships retrofit with double hulls. The trend of increased automation on ship bridges began with radar and has progressed to automated radar plotting aids (ARPA), electronic chart display and information systems (ECDIS), ARPA overlay on ECDIS, and fully integrated bridges. In addition, automation will soon alter how voyage plans are developed and carried out by aiding mariners with expert systems that contain the knowledge of experienced masters and mariners. Automated systems have the potential to reduce physical and certain types of repetitive mental workload (e.g., position fixing); however, automation may place additional demands on the operator's level of attention or use of memory, and can potentially *increase* the cognitive workload of the mariner. Thus, it is important to assess the extent to which automated navigation and control systems contribute to safety by reducing error-prone repetitive tasks performed by humans, and the extent to which they place new and possibly greater demands on the limited capacity of human operators to process information. Recent analyses by Battelle suggest that technologies such as ECDIS may increase workload by virtue of the multiple functions the systems can perform.

The principal issues to be addressed are (1) the measurement of baseline workload and safety performance, and (2) evaluation of the extent to which certain automated systems, such as integrated bridges, automatic dependent surveillance systems (ADSS), automatic docking equipment, ECDIS, and other technologies reduce workload and enhance safety. The focus of this work would be on technologies that have the potential to offset some of the operating circumstances that are specific to Alaska shipping, such as chronic foul weather in the winter months (e.g., automated docking systems), and floating ice in the early spring (radar/ECDIS enhancements). The goal of the work is to define the extent to which workload can be reduced or distributed by automation, and to develop countermeasures for potential human errors that automation would induce.

Suggested Research Methodology

The main research tools in the study of automation and technology are task analysis and human error analysis. These tools are combined with observations of operations of existing equipment and prototype automation to determine how workload and human error potential changes. Task analysis and human error analysis have been applied in an on-going program sponsored by the U.S. Coast Guard, which is further described in Appendix C. This program has focused on individual pieces of equipment, such as ARPA and ECDIS. It is recommended that the methodology be extended to include control-based systems that maneuver the ship in response to programmed vessel courses (i.e, integrated bridge systems).

Timelines/Timeframes

This project would take place over a 24 month period, and would involve interface to on-going federally funded work.

Expected Results

The general results of this project area will be guidelines and recommendations on the implementation of new technologies such as integrated bridges, automatic docking systems, communication protocols and cargo measurement equipment. The specific form of these guidelines will be in terms of equipment-user interface design, and countermeasures for human error.

4.8 Training

Most interviewees identified training as an area worthy of investigation, e.g., the utility of intact crew training for bridge resource management, training on new technology, and the utility of personal computer-based simulators for continuing training. A key area identified by the interviewees was training in the use of automated systems. It was frequently reported that computers and other automated systems were installed aboard vessels with a minimum of training, and that much of the learning that took place was "on-the-job."

Suggested Research Methodology

Because training is such a broad area, the research methods span a range of training-related problems. Investigations of methods for training team performance (bridge resource management) include subject matter expert assessment and simulator exercises. Training in automated system functioning requires application of the tools of Instructional Systems Design (ISD) to determine what needs to be trained, and how best to offer the training. Battelle has prepared potential methods for evaluating these training questions in connection with its on-going work in maritime human factors; detailed descriptions of these are provided in Appendix D.

Timeline

Evaluations of alternative bridge resource management training approaches could be accomplished in a 12 month period. A comprehensive approach to training for automated systems would require approximately 36 months.

Expected Results

The results of this research area will include training strategies for bridge resource management and team performance, and potentially, exercises for continued development of those skills in the operational environment (i.e., practice regimes). For training automated systems, the results will include a definition of what mariners need to know regarding new systems, scenarios for conveying that information, and specific automation training course content and regulatory agency approval criteria.

4.9 Facilities and Inland Marine Transport

A few interviewees suggested that human factors research topics related to terminals and facilities would be of interest. Specifically, these interviewees suggested studying:

- the interfaces between the terminal and the vessel, to determine if appropriate "handshakes," communication patterns, information sharing, etc. were occurring,
- the safety and effectiveness of inland marine transportation (primarily barge traffic) in the State of Alaska, particularly of petroleum products and hazardous chemicals, as well as
- the safety and effectiveness of Alaska storage facilities, including those on native lands (i.e., identification of leaks, a systems of risk analysis of the inland marine transportation system, safety guidelines for such a system, requirements for pilotage).

Timelines

Each of the three research projects listed above could be completed within a 12 month time period.

Expected Results

The results of these research projects could be expected to provide analyses of (1) patterns of actual and desired communications and information sharing between shoreside facilities and shipboard personnel, (2) the inland marine transportation system in Alaska, and (3) the safety and effectiveness of Alaskan storage facilities, including those on native lands. Such analyses are important components of comprehensive assessments of the complete Alaskan maritime system.

5.0 Conclusions

The human factors research topics identified in this needs assessment can be classified into two broad categories: (1) those with a focus on the individual human operator, and (2) those with a focus on systems, organizations and policies. Table 2 presents a classification of the human factors research topics identified within this framework.

Table 2. Human Factors Categorized by Focus

Individual Human Operator Focus	Organization/System Focus
• Personnel Skills, Resources and Certification	• Changes in the Maritime Industry
• Fatigue	• Individual and Organizational Behavior
• Automation and Technology	• Policies and Regulation
• Training	• Oil Spill Response
	• Facilities and Inland Marine Transport

This classification is instructive, since in validates the fundamental premise of human factors research, i.e., the individual operator works within a complex system. Any comprehensive approach to human factors problem-solving must involve both the individual and organizational elements.

The priorities of these research topics should be determined largely on the basis of the ability to complement and coordinate with on-going research programs. The appendices to this document contain information concerning active or planned maritime human factors research. The RCACs can use this information to determine where best to direct research activities funded by Alaska resources.

APPENDIX A: Task Analysis and Manning Studies

Several on-going and recently completed research efforts address the task analysis and manning studies that could provide information relevant to Topic 4 - Personnel Skills, Resources and Certification. A tanker-specific study was undertaken by the Volpe National Transportation Systems Center (VNTSC) to determine the utility of requiring a tanker endorsement for personnel working aboard ships transporting crude oil and oil-based product. The initial portion of the work determined that there were no extant job and task descriptions specific to the tanker trade. Thus, the research team undertook a job and task analysis of tanker deck and engineering officers, and compared the results with the training and certification requirements specified in the Code of Federal Regulations (CFR) 46 Part 10 (established regulation), the International Maritime Organization (IMO) Standards for Training, Certification and Watchkeeping (STCW), and the proposed 46 CFR Part 13 (Tankship Endorsment). The results indicated that while industry tends to ensure that licensed personnel exhibit appropriate knowledge and skills as a requirement for employment, that current regulation does not ensure such knowledge. It was recommended that all licensed personnel working aboard tankships should have a tankship endorsement as specified in the proposed 46 CFR Part 13.

An area of substantial concern in the past 5 years is the issue of shipboard manning. A study commissioned by the USCG and MARAD, and carried out by the National Research Council (*Crew Size and Maritime Safety*, 1990) addressed this issue by indicating that shipboard manning is essentially a human factors issue, and needs to be based on a rational, task analytic or functional approach. Further work by Battelle (*Modeling Techniques for Shipboard Manning: A Review and Plan for Development*, 1993) described the benefits and limitations of various quantitative approaches to shipboard crew size assessment. Currently, a joint Battelle and RPI effort is underway to develop a crew function-based process for determining crew size and work hour compliance. This process will form the basis for a computer-based tool that will facilitate the configuration of crews for different vessel sizes, trade routes, and levels of automation.

Studies that are planned as follow-up to the on-going effort include additional field work to collect specific data on task frequency, task duration, and skill requirements. This information will then be used to enhance the existing task analytic database (derived on the basis of subject matter expert input) to improve the precision of the manning model.

APPENDIX B: Fatigue Studies

The USCG plans to undertake a detailed study of fatigue in U.S. flag merchant marine ships during 1995. The following discussion is derived from the statement of work developed by the USCG for Battelle to carry out.

Background

It has been estimated that approximately 80% of all marine casualties are caused by or contributed to by human error. Often, when casualties are further investigated, it is revealed that work or environmental conditions predispose the operator to make errors which result in accidents. One of the primary predisposing factors is fatigue. Fatigue can result from such things as chronic sleep loss over the course of a voyage, work during night and early morning hours when human alertness is reduced, work in harsh environmental conditions, or from intense work over short periods of time as in port operations.

In response to fatigue-related casualties, work hour limitations have been enacted (e.g., OPA '90). Unfortunately, the data used to establish such laws and regulations have significant limitations. First, due to the lack of data from the maritime industry, current regulations are based on tradition as well as on data from other areas such as Navy warships and submarine, and shiftwork research. Given the differences in work schedules and operational requirements in the maritime environment from these other areas, such generalizations may not be appropriate. Second, current regulations assume that all personnel on board a ship experience identical amounts of fatigue and require a similar recovery period. This assumption is very likely to be false, since there are a variety of duty requirements which not only vary the crews' exposure to work intensity and duration, harsh environmental conditions, and night and early morning operations but also allow some a full eight hours of sleep during the night, while others not. Additionally, some trade routes, such as the Alaska oil routes which have chronically foul weather, cause mariners extreme physical fatigue due to sleep loss and balance compensation. Little is known about what may constitute a sufficient period of recovery under these conditions. Third, current work hour regulations are based on the issue of "how long" a job is performed. However, recent research suggests that "when" (i.e., at what time of day) a job is performed is just as important, if not more so, than "how long" a job is performed, in terms of the effects on sleep duration and fatigue.

To date, there has been very little effort to empirically assess the effects of marine work environments on crew safety and performance. A recent literature review of maritime human factors research revealed that of 97 entries only 8 demonstrated quantitative relationships between crew adaptation variables and work characteristics. This review suggested that until more empirical data of human factors issues in the maritime environment are available, regulation will continue to be "based on tradition, political economics, and relatively uninformed by marine safety human factors data.

Preliminary reviews of the maritime scientific literature, as well as interviews with experts in the marine field have identified Operational and Organizational Characteristics (OOC) which are believed to predispose crews to casualty situations (Attachment 1). Additionally, human psychophysiological responses used in previous research on adaptation to work environments, Crew Adaptation Responses (CAR), are also identified (Attachment 1).

The objective of the current study is to collect empirical data during at-sea trials to assess the impact of OOCs on CARs. Of special interest, is how watchkeeping schedules impact crew safety and performance. Once these data are available, they can be used to evaluate current work practices, provide "baseline" data for assessing the effects of alternative operational/organizational policies, and evaluate present and/or future work-hour regulations. These data will provide quantitative estimates of the effects of marine work characteristics to supplement the current qualitative and anecdotally based, marine database.

This project is intended to assess, empirically, the effects of merchant marine work environments on crew safety and performance. At-sea trials will be conducted to collect empirical data to assess the impact of OOCs on CARs. Of particular interest are the effects of various watchkeeping schedules on crew safety and performance. This effort includes services for measurement tool development, data collection. entry and analysis, and documentation. Also, travel to and onboard merchant marine vessels for at-sea trials is included.

Technical Approach

This delivery order will be conducted in five tasks, as follows:

1. Development of a research plan
2. Development and testing of measurement tools
3. Data Collection
4. Data analysis and interpretation

5. Reporting

The following sections provide the details of each of these tasks, and estimated levels of personnel effort and travel.

Task 1: Development of a Research Plan

The overall objective of this research is to provide data concerning shipboard operations that can be used to establish regulations and operational guidance. A proximal objective is to demonstrate that appropriate measurement tools can be developed and such data gathered. There is evidence from the aviation and other operational communities that appropriately developed measurement instruments and strategies facilitate the demonstration of operational effects on fatigue (*Human Factors*, 1994, Vol. 36(2)). Further, evidence from the maritime community suggests potential fatigue reduction strategies, such as "close watch" systems that permit an extended rest period.

In collaboration with the COTR, Battelle will prioritize and select OOCs for at-sea trials. The 2-3 OOCs, which have the potential to produce the greatest impact on CARs, will be selected to identify vessels for at-sea trials. While the selection of OOCs for at-sea data collection will be based primarily on potential impact on CARs, consideration must be given to accessibility of these data. In other words, one must consider not only the importance of the OOC but also whether there is a valid and reliable method for collecting these data.

Subtask 1.1- Assess Measurement Instruments

Battelle will review select marine research and fatigue/adaptation literature to identify measures that have been successfully employed in various operational contexts. The review will focus on self-report measures, such as activity logs, diaries, and rating scales. Additionally, system-level variables that show a demonstrated relationship to operations will be reviewed (such as incident reports, accidents, etc.). The measurement instruments will be reviewed and rated according to the following criteria: sensitivity to OOCs, validity, reliability, sensitivity to CARs over time, sample size requirements and ease of administration. Because of the nature of ship crew schedules (individual voyages of 5 - 14 days and tours of duty from 60 - 75 days), particular attention will be devoted to tools that can be self-administered over time, following an introductory training trip aboard each of the participant ships.

Subtask 1.2 - Define Resources for At-Sea Data Collection

Because the purpose of this work is to demonstrate the impact of operational characteristics on CARs in the field, the cooperation of shipping companies and their crews is essential. In this subtask, Battelle will contact the management of commercial shipping companies with U.S. flag ships, and describe the purpose and nature of the research project to enlist their assistance in providing access to ships and crews for longitudinal data collection. This subtask will also be concerned with establishing the extent to which variation along OOC dimensions is present within and across shipping companies. This information will help to design the data collection strategy. Initial contacts will be made through the members of the Ship Owners Cooperative Program (SOCP); other information will be collected on the basis of Battelle's contacts within the industry.

In addition to making industry contacts, this subtask will entail consulting with at least two key researchers who have conducted field investigations of fatigue in the aviation and maritime community (Dr. Mark Rosekind and Dr. Peter Colquhoun). Additionally, research staff from this task will coordinate with investigators conducting a study of fatigue on 47 foot patrol boats.

Subtask 1.3 - Formulate Research Plan

The data concerning measurement tools and available resources for at-sea data collection will be synthesized into a formal research plan. This plan will specify subsequent project activities, including development and testing of measurement tools, the ships and routes to be involved in longitudinal data collection, methods of training crew members for use of self-report scales and for ensuring that quality data is obtained (e.g., research staff on initial ship rides and potential use of maritime academy trainees assigned to sea tours), and analysis procedures that will be applied to the data. The research plan will be developed in collaboration with the COTR, and upon approval the subsequent tasks will be initiated.

Task 2: Development of Measurement Tools

This task will be concerned with developing standardized measurement tools and protocols to be applied in the at-sea measurement. Based on the output of the measurement tool assessment, and the findings regarding ship and crew availability and the feasibility of various types of self-report tools, specific measurement procedures will be developed. The objective in developing these tools is simplicity and face validity from the standpoint of the mariner, i.e., questions or ratings will be phrased in appropriate terminology to facilitate mariner understanding and to give and incentive toward continuous provision of data. We anticipate developing a type of log book or diary with simple rating forms and activity descriptions that can be filled out at various times of day (e.g., going on and off watch, following a rest/sleep period, etc.).

The measurement tools will be pretested on several ships to ensure that they are understood by the crew, and that there are no impediments to providing the data. Lessons learned during the pretests of the tools will be incorporated into revised versions prior to full-scale data collection.

Task 3: Data Collection

Upon completion of measurement tool development, full-scale data collection will begin. The general scenario for data collection will involve having a human factors engineer or human factors technician join a ship for a representative voyage (e.g., Cherry Point to Valdez). During this time, the on-board researcher would introduce the measurement tools and train the crew in their use, monitoring quality and responding to questions as necessary. Mailing packages will be provided to the crew to send data to Battelle at periodic intervals during their duty tour. Review of data received in this manner will alert the research staff to any problems in data quality, and ensure a timely resolution.

We will attempt to gather data from crews as an intact unit, i.e., to obtain data from crews that are at the same point in their tours of duty - preferably close to the beginning. This will allow an assessment of both acute and chronic fatigue, as the ratings change over a duty period.

Ship schedules will be monitored by means of contact with the management of the shipping companies, and periodic visits to the ships will be made while they are in port to discuss any problems with the measurement tools that may arise.

Task 4: Data Analysis and Interpretation

This phase of the research project will focus on summarizing the data obtained from multiple ships over extended tours of duty. The volume of data is likely to be quite large, considering that each ship will measure approximately 20 crew members over a period of 60 or more days, several times a day. Thus, task 4 will proceed in parallel with task 3. Prior to receiving large volumes of data, a "front-end" data entry package will be developed with appropriate spreadsheet and database software. This will facilitate data entry, and interface to statistical programs. Specific analyses will focus on alterations in fatigue or sleep quality ratings as a function of crew position, type of trade, time of year, watch standing schedule, and point within a tour of duty.

ATTACHMENT 1

OPERATIONAL/ORGANIZATIONAL CHARACTERISTICS (OOCs) FOR FATIGUE STUDY:

- Crew size
- Crew work duration
- Crew work schedules
- Crew cohesion
- Crew continuity
- Crew duties/tasks
- Level of automation
- Operational trade route
- Organizational work procedures/requirements
- Sea-tour length
- Type of vessel
- Union affiliations
- Union requirements/restrictions
- Vessel's physical condition
- Vessel officers' work procedures/requirements
- Vessel's maintenance concept
- Watch-keeping schedule

CREW ADAPTATION RESPONSES (CARs):

- Sleep duration and quality
- Mental and physical fatigue/tired/alertness
- Circadian desychronization
- Accidents/Injuries
- Affective responses
- Substance use (medicine, caffeine, alcohol, etc.)
- Health symptomatology complaints

APPENDIX C: Automation and Technology

The USCG has funded a project concerned with training for automation and technology for the past two years. The principal focus of this project is the development of *methods* which can be used to understand the training needs imposed by automated systems. This methodological focus is necessary because automation and the requirements imposed on mariners are difficult to observe with traditional human factors procedures. The following description is derived from the program overview and executive summary of the first report from this research effort; it describes the impetus for the research program, the details of work performed to date, and how that work will feed subsequent projects.

Background

One of the goals of the Marine Licensing Program is to ensure that all mariners on U.S. commercial vessels are competent to perform their duties. In order to meet this goal, the U.S. Coast Guard (CG) must determine the minimum standards of experience, physical ability, and knowledge to qualify individuals for each type of license or seaman's document, and it must evaluate applicants against these standards.

Automation is becoming more prevalent on ships, affecting areas such as engineering, navigation, and cargo operations. When automation is introduced, the mariner's tasks change: certain manual tasks may no longer be required, and there are new tasks specific to the operation of the automated system. In some cases, tasks which were formerly performed by two or more mariners are now combined into the responsibility of a single crew member. It is likely that each automated system will require that mariners receive additional training. As the knowledge and skills required to operate a vessel change, the CG should reflect these changes in its qualifications and licensing/certification requirements.

Qualifications and Training for Automated Ships

In order to maintain the safety of our waterways, the CG needs a means to assess how a given automated system changes shipboard tasks and the knowledge and skills required of the crew. The "Qualifications and Training for Automated Ships" project was initiated to fulfill this need. The project involves developing systematic methodologies to determine the impact an automated system has on several aspects of crew performance. Four different, but complementary, methods are being developed.

The first method is *task analysis*. A task analysis technique has been devised which breaks down a shipboard function, such as collision avoidance, into a sequence of tasks. Task analysis is not new; the current approach synthesized various existing methods and adapted them to the maritime operating environment.

The second method is a *cognitive analysis* of shipboard tasks. This looks at the *mental demands* (such as remembering other vessel positions, detecting a new contact on the radar, or calculating the CPA) placed on the mariner while performing a given task. The cognitive analysis identifies the types of knowledge, skills and abilities (KSAs) required to perform a task and highlights differences in mental demands as a result of automation. Cognitive analysis is a relatively new technique, and the application described in this report was developed specifically for this project.

The third method being developed to evaluate the impact of automation is a *skills assessment* technique. It will take the results of the task and cognitive analyses, and will determine the types of training required to instill the needed KSAs for performing the shipboard tasks. These will be compared to current training courses in order to highlight any new training that may be needed.

The fourth and last method is a *comprehension assessment* technique. There have been an unfortunately large number of mishaps in a variety of industries which resulted from an operator's misunderstanding of the capabilities of an automated system. Problems can occur when the operator doesn't understand the limitations of the equipment being used. For example, when the radar signal-to-noise ratio is poor, the ARPA may "swap" the labels of adjacent targets. If the mariner is not aware of this limitation of the ARPA system, he may be navigating under false assumptions about the positions of neighboring vessels, increasing the chances of a casualty. The comprehension assessment technique will identify misconceptions that mariners have about an automated system, which could then be remedied through equipment redesign or training.

The first two of these techniques have been developed and tested; the latter two are currently under development. Together these methods allow us to anticipate the task and training ramifications of automating shipboard systems. The remainder of this summary discusses the cognitive analysis technique and its utility to the Coast Guard.

Cognitive Analysis

Cognitive analysis was applied to a form of task analysis (specifically, an operator function model, or OFM) to produce a powerful new technique for assessing the effects of automation. The OFM task analysis provides a breakdown of a function, such as collision avoidance, into the tasks which must be performed, including a description of the *information* needed to perform the task, and the *decisions* which direct the sequence of tasks. This type of task description is independent of the automation; that is, the same tasks, information, and decisions are required, regardless of whether they are performed by a human or by a machine. For example, in collision avoidance, other vessels must be detected, the relative motion analyzed, and a decision made regarding whether a change is needed to ownship's course and/or speed in order to avoid a collision. These tasks must be performed, regardless of who (human) or what (machine) does them.

The cognitive analysis extends the task analysis by considering the mental demands that would be placed on a human operator in performing these tasks. For example, in order for a human to detect a new ship as soon as it appears (within either visual or radar range), vigilance (sustained attention) and discrimination (the ability to spot a target against the background) are required. The mental demands of determining the closest point of approach (CPA) include plotting a series of target range and bearing, and evaluating the ratio of change. The body of this report provides detailed cognitive analyses for the navigation functions of collision avoidance, voyage planning, and track keeping.

Once the task and cognitive analyses are complete, we can determine which steps are performed by the human and which by machine under different types of systems (different levels of automation). In the collision avoidance example, we find that the calculation of CPA is performed by the human in the radar-and-grease-pencil method, whereas CPA is calculated by the machine in the ARPA method. Therefore, this shows that certain computational tasks are no longer required of the human when ARPA is in use.

It is also important to consider any *new tasks* that are imposed on the human due to automation. For example, the ARPA has an automatic target detection feature, which would seem to be a useful aid to the navigator. However, this feature is prone to false alarms; that is, it tends to acquire many "targets" which turn out to be sea clutter or other things that are not of interest. In this case, then, the cognitive analysis showed that the ARPA does not replace the human in target acquisition, but instead shifts the mariner's task from that of detecting targets to that of validating ARPA targets (and getting rid of "nuisance" targets). Mariners have found the ARPA target detection feature to be so unreliable that it adds to their workload, and most choose not to use the auto-detection feature.

Application of Cognitive Analysis to the Marine Licensing Program

The primary benefit of this technique to the Coast Guard is that it can highlight changes which may be needed in training and licensing/certification. In some cases, the automated system will require new KSAs of the operator. Some of these skills will be equipment-specific, such as how to bring up the correct chart on an ECDIS, or how to perform trial maneuvers on an ARPA. Other knowledge might be technology-specific, such as understanding the capabilities and limitations of different radars. The cognitive analysis technique can be used to identify these KSAs so that they can be considered for possible inclusion in training and testing requirements.

In other cases, the automation will change the relative importance of skills. For example, it was found that the use of ARPA in performing the collision avoidance function virtually eliminated all computational requirements on the mariner, as compared to the radar-and-grease-pencil method. It was also noted that the use of ARPA potentially allows the mariner to keep track of many more targets than before. This suggests that the mariner's task has changed from a *computation-intensive* to an *interpretation-intensive* one. The cognitive analysis technique was then applied to a set of questions taken from a practice test for the radar observer certification. Of the 40 test items analyzed, 30 (75%) were found to test computational skills, while the remainder tested interpretive skills. Given the widespread use of ARPAs on commercial ships, and the influence of ARPA on the skills required for collision avoidance, *it would appear that there needs to be a shift in emphasis from computational to interpretive questions on the radar observer certification exam.*

Training and qualifications are not the only areas that can benefit from the application of cognitive analysis. The cognitive analysis technique can be very useful in pinpointing system design flaws. The cognitive analysis of voyage planning showed that *the particular ECDIS under study was not designed properly to support this task.* For example, in the initial stages of planning a voyage, the navigator is best served by a large-scale chart which encompasses the entire area to be traversed. While this is possible with paper charts, it was not possible with the ECDIS studied. The ECDIS required the navigator to view a series of smaller charts. ECDIS also imposes display manipulation demands such as panning and zooming. These extraneous operations, and the relatively slow and choppy sequence of chart presentation in ECDIS (compared with rapid glances at different areas of a paper chart), interfere with the navigator's ability to conceive of and construct a voyage plan. Several other ECDIS problems were identified, most of which could have been avoided if the developers of the ECDIS system had used an OFM-cognitive analysis approach to understand the information the navigator needs to prepare a voyage plan.

This approach can also be useful in identifying design limitation in the marine system as a whole. The cognitive analysis of track keeping found that the ECDIS was capable of performing the entire function, thereby freeing the mariner from this chore. However, due to legal constraints within the marine system, mariners cannot take advantage of this ECDIS capability. Currently, paper charts constitute the legal record of a voyage. Therefore, manual track keeping must be performed. *In order to make ECDIS a viable alternative to manual track keeping, regulations would have to be changed.* The International Maritime Organization (IMO) is considering this issue in its development of ECDIS Provisional Performance Standards.

Finally, cognitive analysis can be used to generate information pertinent to crewing decisions. The results of a cognitive analysis can help focus attention on potential workload problems and suggest whether multiple crew members might be required to perform a given function.

Thus, there are many potential benefits to employing the cognitive analysis methodology. Because of the specialized psychology and human factors knowledge required to employ this tool effectively, it will initially be implemented through the RDT&E program. Current plans for the Qualifications and Training for Automated Ships project include analyses of automated bridge and cargo-transfer systems (selected with HQ guidance). Cognitive analysis, in conjunction with task analysis, skill assessment, and comprehension assessment, will provide the Coast Guard with a rich and focused view of the impact of automated systems on crew performance and recommend specific changes that may be needed to training and licensing requirements, as well as to system design and manning.

APPENDIX D: Training

Training can be considered the one of the final products of research programs focused on task analysis (Appendix A) and automation and technology (Appendix C). Indeed, these areas are so interrelated as to make their separate descriptions somewhat artificial. It is probably more appropriate to think of these research areas as steps within an overall process of determining training needs and implementing them. The following description outlines an integrated research program aimed at training for automated systems that will eventually replace aging individual navigation and control components. The program that is described is conceptual, but can be considered as the proper direction for integrated maritime training efforts.

Background

Currently, training for advanced systems may lag behind their introduction into the operational environment. For example, ECDIS is beginning to see greater application in commercial operations, although training program developers are only now beginning to consider how to provide preparatory instruction. In recent observations aboard the *Silja Serenade*, the Battelle team learned that automation training is primarily done on the job. Automation alters the way expert mariners perform their jobs; thus, there is no experience base for an integrated approach to training for automation. This is because traditional training analysis techniques have focused principally on the *observable and directly accessible* aspects of human performance in defining KSAs. Concomitant developments in the human factors of automation have stressed the need for understanding mental models developed by operators of automation systems.

Instructional Systems Development (ISD) provides a useful framework from which to address automation-specific issues. The sequence of tasks in this framework begins with analyzing training needs and moves to designing instructional objectives, developing specific training delivery approaches, and implementing the training. Training for shipboard automation requires combining knowledge of the subtle cognitive structures and processes demanded by automated systems with the training analysis and development procedures of ISD.

Technical Approach

Figure 1 illustrates the overall technical approach, showing the process and products of this program. The process will involve identifying the cognitive implications of automation and combining them with the logical process of ISD to identify specific training needs and methods. Shipboard, simulator, and laboratory studies will be used to address these issues and to specify what should be trained and how. The approach described here can be applied both to commercial maritime and USCG training. The discussion that follows focuses on the training needs analysis and design phases of the ISD model. We believe that this focus is critical, because identifying the covert mental processes and error potential of automation requires the application of knowledge acquisition and cognitive task analysis procedures.

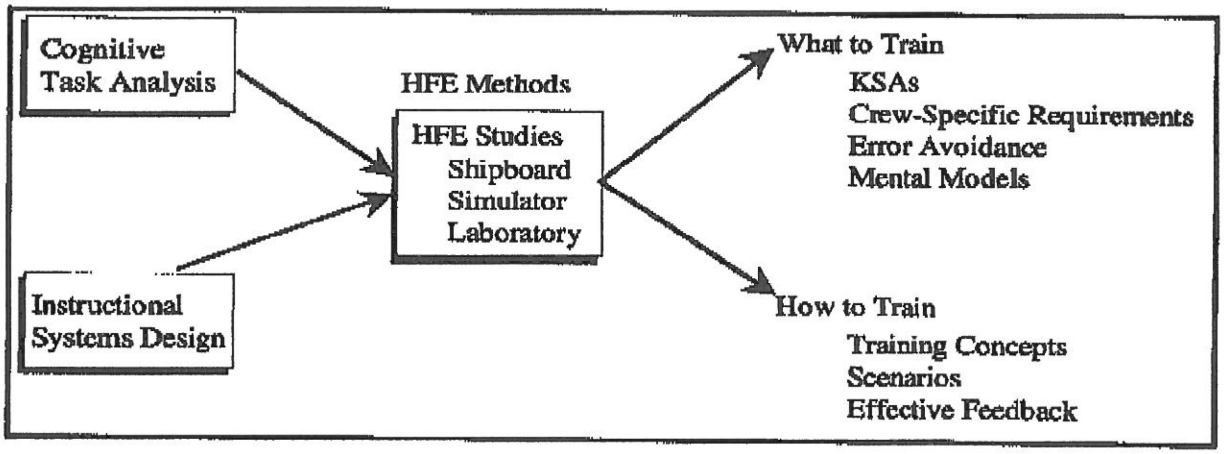

Figure 1. Research program for shipboard automation training

Training Needs Analysis

This phase of the research program will be concerned with identifying the specific ship crew members using automated systems and the specialized KSAs necessary to operate that equipment. The training information needs will range from equipment-specific data to the time periods required for effective learning. Thus, the analysis phase will cover operationally specific concerns, as well as fundamental issues of human information processing related to training strategies.

Shipboard Observations and Cognitive Task Analyses

Shipboard observations will be used to document the task requirements of personnel in the deck and engineering departments, such as voyage planning, collision avoidance maneuvering, and preventive maintenance. Critical incident and cognitive task analyses will be applied to automated systems that are either in the planning or prototype stages. Prior work has demonstrated substantial changes in the cognitive complexity of navigation tasks when performed by ARPA or ECDIS and suggests that new or additional KSAs are necessary. Further, our observations suggest that maintenance of computer-based electronic equipment is an issue of growing concern; this type of maintenance is fundamentally different from that performed by ship engineers.

Specific automation-dependent KSAs will be identified on the basis of critical-incident interviews, shipboard task analyses, and automated equipment cognitive task analyses. The cognitive requirements of automation training can be conceptualized in terms of *equipment, task, and organizational knowledge*. *Equipment knowledge* refers to the need to learn how to traverse menu systems and engage different automated functions. For instance, operating an ARPA requires knowledge of how to manipulate the interface to find targets and select point-of-closest-approach data. Mariners must also possess *task knowledge* such as rules of the road and *organizational knowledge* to coordinate technical and crew resources.

The automation-based KSAs will be used to obtain ratings from groups of maritime subject matter experts (SMEs) to establish the relative importance of KSAs in various equipment and task scenarios. For example, it may be most important to have knowledge of potential ARPA display ambiguities when operating on short ranges in heavy traffic. The SME panel will be conducted for all deck and engine tasks identified and for the operation of classes of automated equipment currently under development, such as expert-system-based maneuvering automation systems, integrated bridge systems, and deck-centralized machinery controls. Additionally, observations and content analyses of shipboard training provided by vendors of automated equipment will be conducted.

Simulator Studies

Simulator studies will be used to define the effects of automation on mariner performance. This definition involves developing an understanding of the kinds of errors mariners make with new technology. Examples of automation-related human factors problems that can be effectively investigated in ship simulators include: (a) the impact of new chart or radar technologies on navigation and collision avoidance, (b) the extent to which skills decline, and (c) how team work structure is changed.

Defining automation-performance effects will be accomplished by running comparison studies evaluating missions with and without automation. Recent studies of this type indicated *enhanced* mission performance with electronic charts and a pilot-expert system. However, these studies evaluated performance when the automated systems were fully functional. The approach to be used in this proposed set of studies will be to design scenarios of varying complexity to be run with automated systems in varying modes of degraded performance. This can span a range from a noisy GPS signal to full ECDIS/ARPA failure. Based on the findings of this type of study, additional training requirements can be identified, such as the need for situational awareness in terms of the state of a particular device (e.g., autopilot) and training for degraded modes of operation.

Laboratory Experiments

Laboratory studies offer a way to understand the more basic aspects of learning, which can be used to facilitate training in shipboard automation. There are fundamental training issues about which very little is known, such as the amount of time required to learn to use an automated system with proficiency and the extent to which underlying manual skills degrade. An example of this is provided by a sophisticated ship propulsion and steering system control that Battelle observed aboard the *Silja Serenade.* This controller provided stick-mounted manipulation of four thrusters (bow and stern), two main engines, and two rudders. A question routinely posed by the *Silja* line navigators is how often they should practice operating the individual control units in order to retain their skill. Similarly, they point out that there are individual differences in how quickly proficiency is attained with this automated propulsion device.

Laboratory experiments are a useful way to address the aforementioned questions. To do so, a simplified model of a *Silja*-type integrated controller will be developed for the laboratory. This model will employ a form of visual tracking that approximates a higher order control system. The system can be controlled with individual thrust and steering mechanisms or with an integrated controller. Issues of proficiency will be evaluated on the basis of the time required to attain a performance criterion; retention of skills will be evaluated by inserting periodic breakdowns of the integrated controller and observing performance degradations. More general application of laboratory methods will involve evaluating training concepts such as error management and exploration training, in which operators are encouraged to "discover" automation concepts and operations and to develop measurement criteria to apply in field studies of automation.

Integration: Training Design, Development, Implementation, and Evaluation

This phase of the program will be concerned with synthesizing the information obtained in the detailed training needs assessment for shipboard automation. Based on the KSAs and error potentials identified in shipboard observations, simulator studies, and laboratory experiments, explicit training objectives will be designed. Examples of these include: "Understand the use of display decluttering to focus on risky ARPA targets" and "Demonstrate ability to manually control ship in the event of multiple thruster/rudder controller failure."

These objectives will be matched to training modalities that are derived from instructional theory. For example, visually distinguishing ARPA and ECDIS target display data is a perceptual-motor task that will best benefit from hands-on practice with appropriately spaced repetitions to establish skill. The integration of equipment, task, and organizational knowledge will focus on developing conceptual models of automated system dynamics and will combine simulator scenarios with computer-based multimedia instruction. This latter approach will employ self-paced instruction in combination with computer graphics to show the "system state" of automated equipment in various scenarios. This phase of the program will develop alternative training strategies that can be evaluated during implementation. For example "passive learning" has been shown to be an effective use of marine simulation. Similarly, cognitive feedback focuses on the mental processes leading to performance outcomes and has been shown to be superior to simple performance feedback.

Implementation and evaluation of training for automation will be based on collaboration with training institutions. Based on the research findings, Battelle will work with maritime training schools and facilities to develop alternative approaches to automation training by integrating content on automation with existing ARPA and bridge resource management (BRM) courses. Battelle will provide the general specifications in terms of training needs, objectives, and alternative strategies. Instructional developers in the training facilities will develop the specific instructional programs. Alternative approaches to teaching the same material will be implemented (e.g., with or without passive learning or cognitive feedback). Evaluation of the alternative approaches will be based on student feedback, performance during simulator exercises (e.g., automated thruster/rudder control failure), and traditional written tests of knowledge. Data from this phase will allow the USCG to develop guidelines for automated system training and criteria for course approval.

Schedule and Expected Products

This technical approach is designed as a 3-year program. The relationship between the program elements and anticipated products is shown in Figure 2. Following the ISD model, the training needs assessment will be conducted in the first 1.5 years. This will be followed by the design of specific objectives and training strategies and their implementation within existing mariner training. Evaluation data on alternative training approaches will result from the implementation phase. The specific products of the research program include:

- Definition of broad classes of KSA for various types of automation and personnel
- Ratings of importance and criticality of KSAs for engineering and deck personnel

- Matching of equipment-KSA requirements to routine and infrequent operations (critical incidents)
- Definition of automation-induced errors
- Scenarios to convey automation concepts
- Strategies for training mental models incorporating equipment, task, and organizational knowledge
- Automation training course content and approval criteria

Finally, in addition to training program content and strategies, the technical approach will also yield important HFE design principles to guide future development of automated shipboard systems.

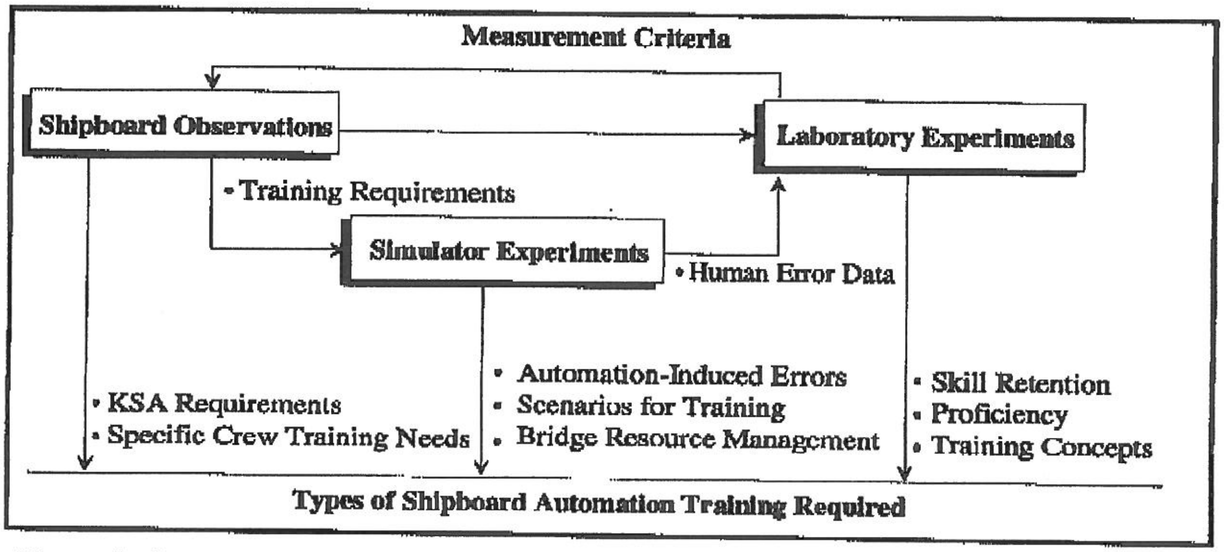

Figure 2. Relationship of research program methods and results