Personnel Performance Workload Modeling for a Reduced Manned Bridge:

Lessons Learned

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Declining budgets and decreased military personnel strength have provided major reasons for reducing shipboard personnel. The specific objective of this project was to develop a "proof-of-concept" for assessing performance workload levels of operational shipboard personnel to be used in the rapid prototyping of ship designs for reducing shipboard manning levels. A review of shipboard reduced manning efforts and development of the "Entering San Diego Harbor" scenario are described. Personnel performance workload models, using this scenario, were developed and exercised for this project. The lessons learned in developing this scenario and moment-to-moment fluctuations in workload data are described for three bridge crew configurations. Three appendices describe a review of human performance models, additional literature related to personnel assessment technologies and personnel costs models, and the bridge team functions and tasks used in the nine member bridge team workload model.

This effort showed that personnel performance workload levels can be measured under current and reduced manning levels, either with or without automated equipment. Workload modeling would provide valuable information to assess current and reduced manning configurations, and operational exercises readiness. Workload modeling could contribute to the objective evaluation of automated equipment implementation and crew member reduction.

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Foreword

This report describes the work that this Center did under the Manpower Assessment Technologies (MAT) project, during FY95 and early FY96. The reimbursable funding was through the Naval Surface Warfare Center, Carderock Division (NSWC/CD), Program Element 62702E, Task Area RDDARDDAAA, from the Ships System Automation Program, Marine Systems Technology Office, Advanced Research Projects Agency.

The NSWC/CD points of contact were Mr. Timothy Smith and Mr. Lance Flitter. Other participants in the MAT project included Mr. John Lockett and Dr. Laurel Allender, Human Research and Engineering Division (HRED), Army Research Laboratory (ARL), Aberdeen Proving Ground, MD, and Dr. Bruce Coury, Johns Hopkins University, Applied Physics Laboratory, Laural, MD. Additional coordination was done with Mr. Robert Bost, Naval Sea Systems Command, Human Systems Integration Division (NAVSEA 03D7), Mr. Frank Pearce, OPNAV N863D, and Mr. Bruce Wintersteen, NSWC/CD.

This report includes the lessons learned in developing a scenario to exercise human performance workload models, as well as presenting moment-to-moment fluctuations in workload indices data. Workload data are presented for three configurations of bridge crew numbers and equipment: (1) existing bridge team of nine members aboard a DDG-51 class ship; (2) a reduced bridge team of three members without automated equipment added to lessen workload levels; and (3) a reduced bridge team of three members with automated equipment added to lessen workload levels. Three appendices, relevant to the MAT effort, include a review of human performance models, additional literature related to personnel assessment technologies and personnel cost models, and the bridge team functions and tasks used in the nine member bridge team workload model.

The Navy Subject Matter Experts making a substantial contribution to the development of the model scenario were QMC(SW) Richard W. Husted, Division Officer, QMC(SW) Daniel A. Glazier, QM1 Terence J. Brew of the Ship Control Division, Fleet Training Center, Naval Base San Diego, and Garry Kincaid, CPO (Ret.), and other personnel of the Shiphandling Complex. Mr. Rick Archer and Ms. Beth Plott, Micro Analysis and Design, Inc. provided the contract support to HRED/ARL for this model development effort.

The objective of the MAT project was to develop a "proof-of-concept" capability for assessing workload levels of operational shipboard personnel.

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Summary

Background

Declining budgets and decreased military personnel strength have provided major reasons for reducing shipboard personnel. The primary objective of the current Manpower Assessment Technologies project was to improve the affordability and mission effectiveness of naval ships through better application of personnel performance measurement in ship design. The required shipboard manning reduction will be obtained through the ship design process.

Objective

The specific objective of this project was to develop a "proof-of-concept" capability for assessing performance workload levels of operational shipboard personnel. Such workload levels could be used in the rapid prototyping of ship designs, with emphasis on reducing shipboard manning levels.

Approach

A review of earlier and current shipboard reduced manning efforts will be described, along with the development of the "Entering San Diego Harbor" scenario. Personnel performance workload models, using this scenario, were developed and exercised for this project. The lessons learned in developing a scenario to exercise human performance workload models, as well as moment-to-moment fluctuations in workload indices data will be described. Workload data will be presented for three configurations of bridge crew numbers and equipment: (1) existing bridge team of nine members aboard a DDG-51 class ship, (2) a reduced bridge team of three members without automated equipment added to lessen workload levels, and (3) a reduced bridge team of three members with automated equipment added to lessen workload levels. Three appendices describe a review of human performance models, additional literature related to personnel assessment technologies and personnel cost models, and the bridge team functions and tasks used in the nine member bridge team workload model.

Results

The current bridge team modeling effort demonstrated that personnel performance workload levels can be measured under current and reduced manning levels, either with or without automated equipment being implemented.

Conclusion

Such workload modeling efforts will provide valuable information to assess current and reduced manning configurations, as well as readiness during operational exercises. Human performance workload modeling could also provide important "what if" personnel information

for the design of new ships, and implementation of automating equipment on new ships, such as the SC21, Arsenal Ship, LPD-17, and CVX.

Recommendation

It is recommended that current Navy ship design and building programs, including the Smart Ship Project, adopt modeling and evaluation procedures, which include moment-to-moment workload assessment at the individual crew member level. The use of workload modeling has been shown to be feasible, and could make substantial contribution to the objective evaluation of automated equipment implementation and crew member reduction.

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Introduction

During FY95, this Center participated in the Manpower Assessment Technologies Project. This report documents the lessons learned and what was required to develop background information needed for "proof-of-concept" modeling of workload for the reduced manning of a bridge team.

The overall objectives of the Manpower Assessment Technologies (MAT) project were to improve the affordability and mission effectiveness of naval ships by improving consideration of personnel performance in ship design. The basic concept underlying MAT was the implementation of object-oriented human simulations in rapid prototyping of ship designs. The MAT project supported the Ship System Automation (SSA) program, run by the Marine System Technology Office, Advanced Research Projects Agency (ARPA). Attaining the SSA goal of 10:1 manning reduction aboard ship will require assessment of many broad issues including naval architecture, emerging technologies, new policies, updated procedures, cultural inertia, affordability factors, and the personnel issues of recruiting, assignment, and training.

The role of the Navy Personnel Research and Development Center (NAVPERSRANDCEN), San Diego, in the MAT project was to support the overall objectives by providing technical expertise on personnel issues. These issues took two forms, general expertise in personnel matters and specific expertise in human performance modeling. Such modeling required an estimate of personnel capacity for performance, which varied with ability, training, fatigue, work/rest cycles, and other schedule and workload factors.

Several elements of human performance were identified for potential investigation in the NAVPERSRANDCEN portion of the MAT project. These included sensory, perceptual, and cognitive abilities; visual target, auditory, speech, communication information acquisition; human memory encoding, organization, storage and recall; task performance demand and execution including workload quantification at the intratask and intertask level; task performance fatigue including energy expenditure rates; subjective fatigue; human error, learning, retrieval, and retention curves; decision making with subsequent effectiveness evaluation; environmental stressors; work/rest cycles; physiological abilities and stressors; reactions within context; and group and team performance variables.

The FY95 objectives for NAVPERSRANDCEN first, were to contribute to the conceptual architecture and program plan by assuring that personnel issues were accurately represented in overall MAT architecture and methods for addressing these issues were in the program plan. The second contribution was in the area of preliminary demonstration capability by dynamically representing selected areas of performance modeling to illustrate potential feasibility of the MAT architecture. In addition, NAVPERSRANDCEN was to provide services as an "honest broker" of information and data to the Naval Surface Warfare Center,

Carderock Division (NSWC/CD), identify promising technologies and processes for inclusion into the MAT concept, and participate as a MAT concept development team member. Initially, NAVPERSRANDCEN was to provide performance data to NSWC/CD, which would include published human factors performance and cohort performance data obtained from existing in-house data base records, and from operational training of Electronic Warfare (EW), and Damage Control Assistants (DCA).

During FY95, redirection was received from the sponsor to contribute to a "proof-of-concept" demonstration of personnel workload modeling and assessment. As a result, this Center's effort was restructured. The primary involvement for this Center in the MAT effort was that of reviewing human performance modeling efforts, reviewing historical efforts in the area of shipboard reduced manning, developing the scenario for the workload modeling effort, and analyzing workload data obtained from the modeling effort. As a result of the human performance modeling review and concurrent development of workload modeling undertaken by the Army Research Laboratory, Human Research and Engineering Directorate, the decision was made to use the WinCrew model. At this time, WinCrew was being converted from the UNIX operating system, workstation-based effort named CREWCUT to a Windows operating system on a personal computer. Adequate development of WinCrew was reached to allow running models of current and reduced manning bridge team.

What follows in this report is a review of earlier and current shipboard reduced manning efforts, development of the "Entering San Diego Harbor" scenario, description of the three models that were developed and exercised for the MAT project, and sample data of model results. Three appendices include a description of the National Research Council major review of quantitative human performance modeling efforts, description of other human performance models, other relevant literature, and the functions and tasks required for the full complement bridge team used in workload models.

During the early 1970s, a major program, titled the "CNO Pilot Program For Bridge Manning," was initiated with the specific goal of reduced manning on the bridge of surface ships. Two CNO/VCNO Action Sheets (1972) provided the authority for this program, CNO/VCNO Action Sheet 303-72, titled "R&D to reduce shipboard manning" and CNO/VCNO Action Sheet 333-72, titled "Bridge personnel reductions." Dachos (1974) described the background, rationale, and direction of this CNO program. The program involved 17 ships from the Atlantic and Pacific Fleets, including two aircraft carriers. Personnel procedure and workload changes were made (Lane & Schwartz, 1974), and automated equipment was installed with positive results (Gustafson, 1974). Description of the Test and Evaluation Plan for the Ship Controlman Reduced Manning Concept program was provided by Sniffin (1974). Sniffin, McCammon, Edmondo, Puckett, and Gowen (1976) developed the test plan for the Integrated Bridge System. Time and motion studies were performed on a full-scale mock-up of ship bridges to assess various manning, equipment, and procedure changes for this CNO program (Edmondo, Hall, Schwartz, & Gullickson, 1974).

The goal of the CNO Pilot Program for Bridge Manning was to limit each bridge watch team to five individuals for the ships other than the carriers. These included the Officer of the

Deck, Helmsman, Lookout, Signalman, and Quartermaster. The carriers were requested to limit the number of bridge personnel to 10. The two phased Pilot Program started in September 1972 and concluded with Fleet testing during August 1973. Phase One determined the feasibility of reduced bridge manning through personnel workload and policy changes without new automated equipment, while Phase Two added new commercial off-the-shelf (COTS) equipment, which was "state-of-the-art."

Four approaches were used during Phase One. These included: eliminating function duplication between the bridge and CIC, build and use "watch teams" for increased cross training and small group interaction, use experienced instead of inexperienced personnel, and examine the ship organization to reduce the administrative workload of the bridge team. Even though the reduced manning goals were not met, recommended bridge manning was reduced for conditions III and IV steaming. The Ship Manning Document (SMD) for the carriers specified nearly 30 crew members and between 14-16 members for the other surface ships, depending on the type of ship. Results from subjective comments and reports obtained during this program suggested the recommended bridge manning levels to be 18 members for the carriers and 8-9 members for surface ships, depending on type.

During Phase Two, introduction of several categories of COTS automated equipment was evaluated for improved efficiency and responsiveness of the reduced bridge team members. Included in the equipment were: autopilot steering, automated collision-avoidance systems, automated navigation (OMEGA), several data loggers and recorders, close circuit TV between the bridge and CIC, laser communicators, fog signal timers, and other devices. Substantial reduced workload and increased capability were shown after the introduction of this equipment.

Dachos (1974) concluded:

> The program was ambitious and oftentimes a logistics nightmare, but a
>
> great deal has been learned. Although a program such as this can demonstrate
>
> reduced manning, there is a difficult road ahead before implementation in the
>
> Fleet becomes a reality. The answer lies in the design and the planning for
>
> support of our new ships. We need to take some bold steps. Conservatism and
>
> tradition should not impede good judgment and initiative if we are to make a
>
> dent in this manning problem. (p. 44)

Gaites (1973) reported on areas of design, construction, maintenance, support and social problems of automated merchant ships with small crews. His report also noted recent Navy

experience and discussed short and long range plans of demonstrating ship automation and reduced manning, which were already demonstrated in merchant shipping.

Other major Navy programs continued after that time, which were directed toward reduced manning (Rainey & Fulton, 1974; McCammon, 1976); reduced manning for damage control (Edmondo, 1976); Integrated Bridge System (Sniffin, McCammon, Edmondo, Puckett, & Gowen, 1976); and Shipboard Facilities Maintenance (Schwartz, 1976; Schwartz & Sniffin, 1980). Plato (1974) described the interaction of naval engineering and manpower utilization, including development of a Design Work Study Code from which was later developed the Ship Manning Document (SMD) methodology, development of the Required Operational Capabilities (ROC), and habitability and human factor improvements which contributed to reduce manning.

Often manning levels increased substantially from the Preliminary Ship Manning Document. Nauta and White (1981) used the USS SPRUANCE (DD-963) to examine why requirements relating to manpower, personnel, and training changed after commissioning. Several reasons for the increase in manning levels were noted and included acquisition strategy, and other policy related issues. The authors provided several recommendations based on problems noted at the time, including manpower validation done while at sea, not in port, better identification of training deficiencies, earlier identification of training equipment in the acquisition cycle, and "improve the process for estimating mature manning requirements for new ships by including error or growth margins for workload estimates in preliminary manning documents, and by assessing the adequacy of final estimates through a scenario-driven, dynamic simulation model."

There has been renewed interest lately of reducing shipboard manning levels primarily due to decreased Navy end strength levels and decreased budgets. Bost, Mellis, and Dent (1994) have discussed reduced manning for future Navy ships. Shipboard manning has remained fairly constant for the past half century. They suggest that reduced manning has not been effective primarily due to cultural aspects of the Navy, and less because of technological innovation reasons. Bost, et al. (1994) suggest several technology perceptions which contribute to maintaining current manning levels. These include the facts that automated systems require manual backup, increased maintenance and constant monitoring, computer systems may be unsuited for the harsh naval environment, or software is not reliable. The authors dispel these and other technological impediments to reduced manning. Their main point is that reluctance to reduced manning comes from the existing cultural environment within the Navy. They suggest several cultural "roadblocks" to reduced shipboard manning, including no incentive for the Fleet to change or ship designers to reduce manning, aversion to risk, acquisition costs overriding life cycle costs, and Navy tradition. Bost, et al. (1994) conclude that for reduced manning to be realized, there must be changes in ship design and acquisition procedures, organizational culture to favor automation, input from the Fleet must be made during the ship design phase, and top leadership must encourage reduced manning.

The U.S. Coast Guard established a program in 1994 to establish crew manning requirements aboard their vessels. Lee and Sanquist (1993) provided a review of modeling

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techniques for shipboard manning and described a plan for development to be used by the U.S. Coast Guard. In support of this program, Lee and Morgan (1994) described a task network modeling effort to assess the effects of automation on the entire crew aboard Coast Guard ships. Their emphasis was on "clumsy automation" which may reduce crew workload in one area, but may greatly increase workload for other crew members, especially during emergency situations such as fires, unscheduled maintenance, or reduced visibility. The model would be able to identify possible overload conditions and specify the reasons for such overload condition.

Other reports dealing with shipboard automation and the effects on manning levels for military and commercial shipping have spanned several years (DeBow, 1975; Shishko, 1975; Department of National Defence Ottawa Symposium, 1981; National Research Council, Marine Board report, 1984; Ship operational characteristics study, 1988; Vatikiotis, 1985; Lovelace, 1994). Rothblum, Lee, and Grabowski (1995) have recently described a model which they have applied to assess commercial ship crew size. Workhours, maintenance and crew structure may be examined in the model to assess crew size required for commercial ships. Ship type, port call numbers, tasks, task duration and crew number, type, and assignment information is used by the model to simulate voyage scenarios. Varying this information provides estimates of crew size effectiveness.

Four training methods appropriate for automated ships with reduced crew were discussed by Sanquist, Lee, and McCallum (1995). The four methods included Operator Function Modeling (OFM), Cognitive Task Analysis, Knowledge, Skill and Ability Analysis (KSA), and Comprehension Assessment/Error Analysis derived from task analysis results. They compared the four methods against the criteria of data type, reliability, validity, analyst requirements, economic feasibility, and applications. Sanquist, et al. (1995) concluded that:

> ...as the mental demands of technology increase, training analysts will need to
>
> place greater emphasis in the cognitive and human error areas. By
>
> complementing applications level experience with cognitive and human error
>
> analyses, training can address more of the unseen, and potentially high-risk
>
> aspects of technology operation. (p.1267)

Antochenko, Koshevoj, Lapiy, and Sadiy (1993) discussed automation and reduced manning aboard USSR merchant vessels. They primarily emphasized ship pilot automation and integration of bridge navigation instrumentation.

In order to improve Australian commercial shipping, reports were published in 1982, 1985 and 1986 by the Australian Department of Transport, which promoted increased technology and economic efficiency. Such increased efficiency included implementing new

automation, which could reduce shipboard manning. Other measures recommended included integrating ratings, upgrading skills, and developing a team approach for the crews.

A formal report of a fatal accident investigation on a minimum manned ship was recently done by the Australian Department of Transport (1994). The vessel was the Shelf Supporter, used for offshore oil company supply.

Naval Research Advisory Committee Study for Reduced Ships Manning

Declining budgets and decreased military personnel strength have provided major reasons for reducing shipboard personnel. Recently, the Naval Research Advisory Committee (NRAC, 1995) reviewed and evaluated several issues related to reduced shipboard manning. These included current approaches to shipboard manning, earlier reduced-manning studies, foreign Navy reduced shipboard manning efforts, emerging technologies, and impacts on ship design, training, and policies. Five substantial observations were made by the NRAC Committee which included off-the-shelf hardware, software, and other equipment currently exists for implementing reduced manning aboard ships; there are no legal reasons to not reduce manning with the exception of the posting of a lookout; foreign navies have already implemented reduced manning through the introduction of automated equipment; the Navy already uses automation for training personnel, such as multimedia systems; and current Surface Combatant for the 21st Century (SC21) program would provide an opportune mechanism to implement reduced manning during the design phase of new ships.

The Committee specified six recommendations, which included review all policy directives and further justify or get rid of those which do not encourage reduced manning; revise the Required Operational Capability/Projected Operational Environment (ROC/POE) documents, which specify ship's manning levels, to encourage reduced manning; manpower related costs approximate 60 percent of the budget, therefore "dispel the myth of 'free' manpower; current ship design does not encourage reduced manning, but should through incentives throughout the design process; the SC21 program is in the early design phase and should be highlighted and adequately funded to "revolutionize" ship design for reduced manning; and because advanced technologies are currently available and reliable, the CNO should initiate a demonstration project of new technology on an operational ship.

The NRAC Study concluded that "technology is not a roadblock--manning can be reduced substantially using only demonstrated technology" and "The roadblocks are to be found in culture and tradition..." As a result of the NRAC Committee's last recommendation and conclusion, the CNO has initiated the Smart Ship Project.

The Technical Cooperation Program

The Technical Cooperation Program (TTCP), Subgroup U, Action Group-15 (Human Factors Integration for Naval Systems) includes the countries of Australia, Canada, United Kingdom (UK), United States, and New Zealand. One of the three Key Technical Areas

under consideration includes Lean (Austere) Manning Technology. The purpose of the Lean Manning effort is the reduction of personnel on future ships by using assessment tools to reduce manpower requirements on ship and C4I systems. Australia has no active research in Lean Manning. Canada has no current research, but has developed two tools related to manning requirements, called ERASMUS (Establishment Roster and Simulation System) and MANIAC (Manning Impact Analysis Calculator). ERASMUS is a data base program which provides personnel requirements, weekly task hours, and other information (Donderi, Webster, Hardick, Menard, & Deveaux, 1995). Output from ERASMUS goes to MANIAC to produce ship's cost and volume specifications, obtained from salaries, space requirements, and provisioning. UK has the model "Complement Regime Evaluation for Warships" (CREW, 1995), which describes and predicts future manpower levels, task allocation and complementing. The CREW model is used as a validation, rather than as a manpower reduction tool. Defence Research Agency (DRA), Centre for Human Sciences in the UK has been examining methods of dynamic task allocation and their suitability for future naval systems. Such work is ongoing and will develop new methodology appropriate for future reduced manning efforts. Several recent papers have described efforts in the UK on reduced shipboard workload and reduced manning (Chilvers & Hansom, 1993; Pelly & McKenzie, 1989; Purdy, Martin, & Corbridge, 1995; Tainsh, 1991; Thompson, 1989.) New Zealand has completed a number of subjective exercises to reduce manning. The data produced may be relevant to future reduced manning efforts. There is no ongoing research in the area of reduced manning in the New Zealand military.

Scenario Development

During FY95, redirection was received from ARPA, the project sponsor, to concentrate on providing a "proof-of-concept" demonstration of personnel performance modeling by the end of FY95.

As a result of the human performance modeling review, and a commercial-off-the-shelf human performance workload model about to be available, effort was concentrated on developing a scenario for use in human performance workload model, developed by the Army Research Laboratory, Human Research and Engineering Directorate (ARL/HRED) under contract to Micro Analysis and Design, Inc., Boulder Colorado. The ARL/HRED workload modeling effort, developed for use in evaluating reduced crew members for the future main battle tank, was described by Little, Dahl, Plott, Wickens, Powers, Tillman, Davilla, and Hutchins, (1993) as part of the Crew Reduction in Armored Vehicles Ergonomic Study (CRAVES). Subsequently, the model was modified from requiring a workstation running the UNIX operating system (CRAVES, 1993) to being run on a personal computer running under the Microsoft Windows operating system.

With the help of individuals working on the Surface Combatant of the 21st Century (SC21), a reduced manned bridge team was identified as the candidate for the MAT project workload modeling effort. Background information was obtained to implement the workload models, as well as determine crew member identification, functions, and tasks of the

performing personnel. This information was obtained through study of relevant Navy literature, visitation to the Shiphandling Complex (SHC), fleet contacts, and interactions with Subject Matter Experts (SMEs) from the Ship Control Division, Fleet Training Center, Naval Station San Diego.

Some of the basic Navy information sources used for background in the MAT project modeling effort included *The Bluejackets Manual* (Bearden, 1990), description of contemporary integrated bridges (Bowditch, 1995; Sperry Marine, Inc., 1995); San Diego harbor information (FLEET GUIDE: SAN DIEGO, 1991), Navy Joint Instruction 3530.4 of 1994, "Surface Ship Navigation Department Organization and Regulations Manual;" OPNAVINST 3120.32C (1994) Standard Organization and Regulations of the U.S. Navy; *Operations Stations Book For The DDG-51* (1984); *The Watch Officer's Guide: A handbook for all deck watch officers* (Stavridis, 1992); *Local Notice To Mariners, Weekly supplement*; manning of the DD-963 class destroyer (Nauta & White, 1981); *Jane's Fighting Ships* (Sharpe, 1991); *The Nautical Almanac For The Year 1993*; *Destroyer and Destroyermen* (Yates, 1959); *Automation of ship systems and equipment.* Naval Research Advisory Committee Report, Office of The Assistant Secretary of The Navy (Research, Engineering and Systems), (1989); Autonomic Ship (Ditizio, Hoyle, & Pruitt, 1995); new generation Surface Combatant for the 21st Century (Ewing, Holmes, Rochon, Daley, & Hellman, 1995); *Command at sea* (Cope, & Bucknell, 1966); human factors in warship design (Goodwin, 1990); and *Watch Officer's Guide* (Lee, Brown, & Morabito, 1987).

Shiphandling Complex

The Shiphandling Complex (SHC) occupies B3149 at the Naval Station, San Diego. USN owns the structure, but all contents are owned and operated by MarineSafety International (MSI), under contract with the USN. SHC is managed by a retired Rear Admiral. Several retired former Naval officers and senior enlisted personnel perform the training. MSI is a subsidiary of Flight Safety International, which runs most of the air traffic control simulators for the FAA as well. There are three separate SHCs owned and run by MSI. The first installation was in Newport RI, a second here in San Diego, and a third in Vallejo, CA. The latter is smaller than the first two, with one mockup of a full mission merchant bridge and is run primarily for the California Maritime Academy. The SHC in San Diego was established January 1994.

The SHC maintains a very busy schedule, training crews from at least two ships per week. One crew trains from 0800 Monday through noon Wednesday, while the crew from a second ship trains from Noon Wednesday through 1700 Friday afternoon. Training could also be done during the evening and weekend times. The SHC is arranged into two separate generic bridges and control rooms. Realistic simulations are run from the control rooms using Silicon Graphics computers and multiple monitors. The monitors are arranged to depict very realistic wide angle views of the training situations, whether at sea or entering a port. The visit was timed to be able to observe crew members from the newly commissioned USS RUSSELL (DDG-59) during their training.

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An overview was given by the SHC manager and additional information was provided by the simulator operator. The operator not only operated the consoles, but interacted with the crew members regarding ship control and instruments by giving readouts. SHC bridge was designed as a five man bridge. On the bridge is usually the Conning Officer (OOD); helmsman (Jr. enlisted, E-1--E-3) who handles the rudder control; the lee helmsman, (also Jr. enlisted) who handles the throttles; a helmsman safety officer; radar operator, and the Boatswain's Mate Of The Watch (BMOW), who oversees and rotates the helmsman, lee helmsman, port and starboard lookouts so they don't get bored. On special evolutions such as entering port, a Quartermaster, not necessarily the Quartermaster Of The Watch, enters readings such as bearing, rudder, and speed, into the ship's log. The military ship bridge is contrasted to the Merchant Marine ship, which may use only a single Mate (corresponding to the Conning Officer) and the Able Bodied Seaman (AB), who fixes plumbing and other things aboard the ship. A Master is added when entering and/or leaving port.

Two scenarios were run during the afternoon, entry into port and replenishment at sea. The crews were trained on one scenario and then the second during a 4 hour period. Observations of crewmember-to-crewmember interactions and their interactions with the console operator were allowed on a "not-to-interfere" with training basis. Three Navy Lieutenants from the USS RUSSELL (DDG-59) performed an entry-into-port scenario. When entering port, a speed of 0-10 knots was maintained. Ship speed was varied by propeller pitch up to 11 knots. Above this speed, shaft RPM was varied. With pitch at 100 percent and shaft RPM of 74, a speed of 13.1 knots was obtained. Interaction of variable pitch propellers and shaft RPM increases the complexity of inter-crew interaction and communication. Protocol and giving/receiving of verbal orders follows a very specific and rigid format. Whenever a verbal order was given on the bridge, the very same order was acknowledged verbally and repeated by the receiving individual.

A generic pilot house was configured for the entry-into-port scenario in such a way that a 180 degree field of view was obtained. The three USS RUSSELL crew members assumed the roles of Conning Officer, helmsman, and lee helmsman. A retired Navy Captain was the training facilitator. A second SHC employee was off the bridge functioning as console operator. Equipment included two radar consoles, main wheel console for the helmsman and lee helmsman, and a chart table. Complexity was added to this entry-into-port by avoiding wharves and other obstacles, and transiting narrow channels. After completion of the scenario, the crew was provided with computer printouts of the course transited and errors made. Detailed discussions of the mission were made between the crew and the facilitators.

The second scenario was the replenishment of fuel at sea. A decommissioned oiler (Auxiliary Oiler Replenishment, USS ROANOAKE, AOR7), was used as the replenishment ship during the second scenario. Crew of the USS RUSSELL was tasked to refuel with the USS ROANOAKE. The evolution started with the ships approaching head-on and the USS RUSSELL being tasked to swing about and catch up with the USS ROANOAKE. Much keen judgment was required for this maneuver. Interestingly, the scenario was done in real time and all communication and actions were stored on the computers for scenario discussions when

completed. During the refueling, there was a rudder casualty with the USS ROANOAKE loosing rudder control. The USS RUSSELL was forced to take emergency procedures to stop refueling and break away from the USS ROANOAKE. Rudder control was later regained. Several minutes later the USS RUSSELL lost a man overboard on the starboard side. It took 7 minutes for the USS RUSSELL to turn around. The crewman was saved. Such a scenario would be far too complex for the MAT project performance modeling proof-of-concept, but did provide very realistic ship handling training for the USS RUSSELL crew.

Important lessons learned from the visit to the Shiphandling Complex, San Diego include the appreciation for the training realism now possible through simulation, the complexity of crew member interactions, and the reliance on redundancy to assure verbal communications are correct.

Scenario

The function and task information required to develop the "entry into San Diego Harbor" scenario was obtained from reference material, and information obtained from the Shiphandling Complex, Naval Station, San Diego, and the Subject Matter Experts (SMEs) in the Ship Control Division, Fleet Training Center, Naval Station, San Diego. A small water craft crisis (SCC) was added to provide additional realism to the scenario. The SCC appeared in the scenario near Turn 1, a moorage area for small craft in San Diego Bay. During this crisis, the Bridge Team was required to assess the situation and take evasive action.

Typically, the Navigation Detail and Sea and Anchor Detail are set prior to reaching the Approach Point to San Diego (SD) Harbor. This point is about 1.0 nautical mile (NM) outside the Zulu navigation aid at the end of the Zuniga Point jetty. Ranges and bearings for the scenario were determined from the NOAA marine chart numbers 18765 (Approaches to San Diego Bay, 100000, 1984), 18772 (Approaches to San Diego, 20000, 1983), and 18773 (San Diego, 12000, 1984), and verified from the Micro Mariner For Windows software (DF Crane Co., version 1.07, 1995) developed for the personal computer. The latter software used rasterized NOAA charts, however provided improved accuracy for determining bearings and ranges, compared to hand calculations. Naval navigation uses these charts for entry into San Diego harbor.

Bearing fixes are taken every 2 minutes, but as critical events approach, such as anchoring, the fixes are taken at 1 minute intervals, then at every 30 second intervals. For example, there would be 12 fixes between Approach Point and the Turn To Point Alpha based on the ship speed of 10 knots and 3.8 nautical miles. The scenario started at Point Alpha.

Bridge Team

For this scenario, Bridge Team consisted of Bearing Recorder (BR); Bearing Taker, Port (BTP); Bearing Taker, Starboard (BTS); Plotter (PLOT); Navigation Evaluator (Navigation Officer), (NAV); Officer Of The Deck (OOD); Quartermaster Of The Watch (QMOW);

Helmsman (H; Master Helmsman, MH); Surface Search Radar Operator (RO); and fathometer operator (FO). When referencing both of the Bearing Takers at the same time, regardless of the side of the ship, the notation of "BTs" will be used. All members of the Bridge Team are on a common telecommunications system with the designation JW used for the navigational circuit. The hands of Bridge Team personnel are now free for other tasks, whereas the older systems required pushing a button to talk.

Bearing Fixes

The following is the sequence performed for taking nearly all bearing fixes. Generally, the BTP or BTS closest to the navigation aid would give his bearing first. The navigation aid at the beam is called out first, because of its greatest relative motion. BR, monitoring the clock, says "Standby." Within the next 10 seconds, the FO reads depth (i.e., 27 ft.) and talks on the telecommunication line. The BTP and BTS (BTs), also on the telecommunication line, locate the navigation aids and move ("train") their alidade instruments to take the bearing. The BT, closest to a navigation aid is determined and says "Mark." BTP and BTS give their readings, (i.e., BTP: Alpha @ 275 degrees, BTS: Bravo @ X degrees, BTP Charlie @ Y degrees).

BR now records the bearing data into the log book, but is also repeating this information, which is very helpful, although not essential. There is a very high cognitive load for the BR at this point. It is a very difficult task to listen, record, and repeat the bearing information nearly at the same time. PLOT puts bearing points on the chart. This is all done within 15-30 seconds. Within the next 90 seconds, (fixes every 2 minutes) to the next "Standby," the BR looks at the chart, and the PLOT determines the new navigation aid(s) coming up. The PLOT continually talks to the BTs and alerts them to what navigation aid to expect next. The BTs inform the BR when they see the next navigation aid.

At every bearing fix, the PLOT takes bearing information from the BR and transcribes the information to the chart, determines where the fix is, draws the course line, and puts down the Dead Reckoning (DR) line for the next two fixes. The PLOT also labels course and speed, and determines Set and Drift. Set is how much the ship is off course (direction). Drift is the speed. The PLOT compares old DR with the current status. If there is a problem, PLOT redoes the ship's track. There is high cognitive load during this activity for the PLOT. He applies the divider instrument to the Speed Triangle located on the navigation chart, to make a quick determination of speed (knots), time (minutes), and distance. PLOT continues to interact with the BR so that the BR can determine which navigation aid to relay to the BTs. At this time also, the NAV is looking out the windows at the "real world" for a reality check. He looks at the bearing fix and determines and reports the fix time and accuracy using real world information and the plotter's chart. For example, NAV might say "35 yards to the right of proposed track, hazard "X" ahead on current track." NAV provides information to the OOD for action. Upon receiving information from the NAV, the OOD may initiate corrective action if necessary, such as change course or speed. If the OOD makes changes, he relays these changes to the Navigation Team, including BR and the BTs.

FO may be located remotely, such as the chart room or Combat Information Center, but is critical to the Bridge Team and is in constant communication with the Team. QMOW may not be part of the Navigation Detail, but is keeping logs, and is part of the Bridge Team.

Gyro Error Check

For a Gyro Error Check, the navigation team uses the geographical range between two established items on a navigation chart. These items do not need to be navigation aids, but could include things such as a building or a pier. The Hotel Del Coronado (HDC) Tower cupola is lighted at night and is used often for navigation. The BTs know that a "geographical" range is coming up and tell the BR that they are about to get the range, after which they state the range. For example the BR might say to the PLOT: "Range up on Zulu and Del." Zulu is the light at the end of Zuniga Jetty and Del is the HDC. PLOT determines the exact bearing from the prepared navigation chart. This range is on the starboard side of the ship. As soon as the two point line up, BTS marks the range and reads the bearing. PLOT corrects the bearing for the gyro error, if necessary.

There are two navigation aids in front of Shelter Island. These two aids form the "steering range." If the ship is on course, these two navigation aids line up exactly, so that only one aid may be seen. When the bearing fix for the gyro error check is made in conjunction with another geographical range, such as the two navigation aids lining up in front of Shelter Island light (straight ahead), it is called a "Fix of Opportunity," which is very accurate. At that point, the BTS would "mark" the Zulu-Del range, while the BTP would mark the two aids straight ahead, in front of Shelter Island. The "standby" mark is not made for this type of bearing fix. When the ship is lined up with both the geographical and steering ranges, the fix is noted. PLOT continues to determine the Dead Reckoning (DR) track, while the NAV evaluates the result and relays the information to the OOD.

Turns

There are four starboard turns prior to the Precision Anchorage in this scenario. As the ship approaches each turn, PLOT calls for constant bearings for the turn bearing, where the BTs relay the bearing readings constantly. As noted above, there is constant communication between the BR, PLOT, and both BTs. BR relays the order to stop taking fixes to BTS, but not the BTP. BTS looks at the navigation aid and pans with his alidade. BTS calls out the bearing for the turn every 1 degree. BR doesn't necessarily write down the bearing information, but repeats the bearing readings. PLOT uses the turn bearing information to determine the distance to next turn. NAV advises the OOD what the next course should be. At the proper turn bearing, PLOT says "Mark the Turn" and the BR says "relay your marks." The BTs stop taking marks, stop talking, and take short break. NAV says "Mark the Turn" to the OOD. OOD takes action, relays the order to the helmsman: "15 degree rudder ..." usually done at 10 knots. Ships must slow to 5 knots at Ballast Point, and may resume 10 knot speed at Turn 1. Helmsmen (H) are highly qualified, often with the designation of Master

Helmsmen (MH), and are typically Quartermaster (QM) personnel. MH completes turn. MH is not considered part of the Navigation Team, however is a critical member of the Bridge Team. MH has extensive training to perform many different actions during Casualty Control. The RO is most often used during reduced visibility and will be used in this scenario.

Precision Anchorage

The destination of the ship is always predetermined and the destination is reviewed during the navigation brief prior to entry into the harbor. For this scenario, a Precision Anchoring (PA) will be performed. As the ship approaches the PA, the OOD or conning officer looks up and gets the "head bearing." He already knows the "drop bearing." Because this information is on the charts, there is no need to plot this bearing. The ship is lined up on the "head bearing" at least 1,000 yards away from the PA. By 1,000 yards, the ship speed is down to 5 knots, and bearings are shifted to 1 minute fixes. Within 500 yards, the bearing readings are taken at 30 second fixes. By 300 yards from the PA, the OOD orders "backing bell." At this point the ship is starting to stop. While stopping the ship, constant bearings are given from the chart. A perfect stop is when the ship has stopped, and is starting to back up at the anchor drop area. OOD orders "let go anchor" to boatswain mates for dropping the anchor. When the anchor goes, BR says "mark a fix" at anchor. The BTs give bearings for all navigation aids and the MH marks the compass heading. The plots are made on plastic covers over charts, which are scrubbed clean at this time. PLOT records a bearing fix after scrubbing chart cover. From the fix, PLOT extends a line to the ship's heading and measures the distance from the BT alidade mount stations to the Hawse Pipe, where the anchor chain goes through the hull, to determine the exact location of the anchor. The distance on the ship between the Hawse Pipe and the BT stations is critical, especially for a Precision Anchoring. As the anchor chain is going down the ship starts reversing (backing down) and the chain laid on bottom, but not in a heap. The amount of chain needed is determined from the depth of water times 6. The ship is stopped when two thirds of the chain has been laid out. As the ship pulls on the anchor, the anchor digs in, which is called "setting the anchor." When there is steady and heavy strain on the chain, the ship is properly anchored. More chain may be let out, if needed.

During the PA, the Navigation Team is plotting fixes to make sure that the ship does not move, the anchor is holding, and determine the exact location of the ship. The length of the anchor chain plus the distance of the BTs alidade mount to the Hawse Pipe determines the "Drag Circle." The Drag Circle around the anchor is drawn by the PLOT, after which the Anchor Detail is secured and the Anchor Watch is set.

Bridge Team Scenario Waypoints and Functions

Figure 1 shows NOAA Chart number 18773 "San Diego Bay" with the 15 waypoints starting at Point Alpha (1) through the Small Water Craft Crisis (8) to the Precision Anchor (15). The waypoints in Figure 1 were derived using the DF Crane Micro Mariner software,

and subsequently edited with image processing software (HiJaak TouchUp, Inset Systems Inc., version 3.0).
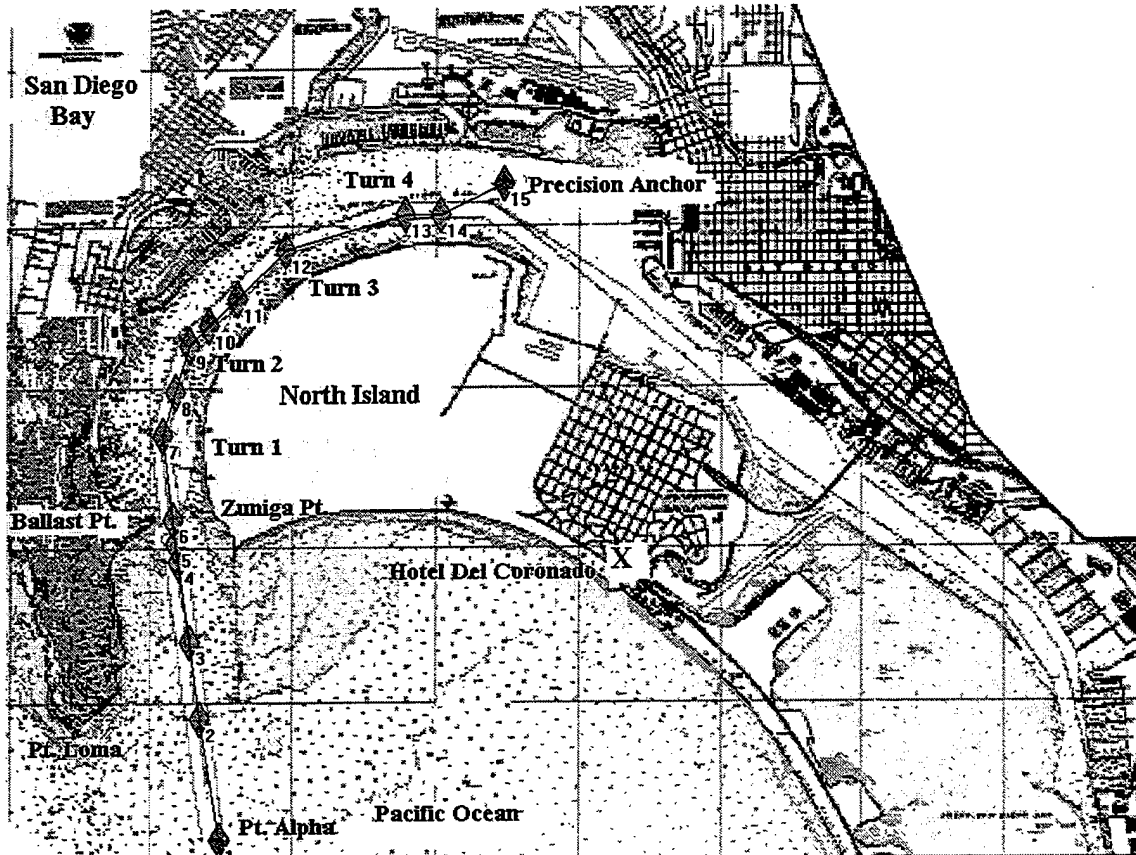
Figure 1. NOAA Chart 18773 showing the scenario waypoints in San Diego Harbor.

Specifications for the 15 waypoints appear in Table 1. Information provided for each waypoint include the latitude, longitude, range to the next waypoint (nautical miles), total range (nautical miles), bearing to the next waypoint, start time of the scenario, and the ship's speed (knots). Buoy numbering follows the NOAA Chart information, such as Buoys G5 (Green) and R6 (red) at the Point Alpha waypoint. Waypoints 5 and 6 are located at Ballast Point where waypoint 5 is at the west end of the Magnetic Silencing Range (WMSR) and waypoint 6 is at the east end of the Magnetic Silencing Range (EMSR). The scenario terminates at the Precision Anchor (PA). Table 1 also shows that the scenario took 1 hour and 7 minutes in real time to transit the harbor to the Precision Anchorage at speed noted for each waypoint.

Table 1

Waypoints for San Diego Harbor Scenario

Waypoint	Lat. (°N)	Long. (°W)	Next Pt. Range (nm)	Total Range (nm)	Bearing to Next Pt. (°T)	Time	Speed (kts)
1. Pt. Alpha G5R6	32 39'09"	117 13'33"	0.78	0.00	353	16:00	10
2. Buoys G7R8	32 39'55"	117 13'41"	0.50	0.78	353	16:04	10
3. Buoys G9R10	32 40'25"	117 13'45"	0.52	1.28	353	16:07	10
4. Buoys G11R12	32 40'56"	117 13'49"	0.12	1.80	353	16:10	10
5. Ballast Pt. WMSR	32 41'12"	117 13'51"	0.15	1.92	353	16:11	10
6. Ballast Pt. EMSR	32 41'12"	117 13'52"	0.54	2.07	353	16:12	5
7. Turn 1 @ G15R14	32 41'44"	117 13'56"	0.28	2.61	15	16:18	10
8. Water Craft Crisis	32 42'00"	117 13'51"	0.30	2.88	17	16:20	5
9. Turn 2 @ G17	32 42'16"	117 13'45"	0.16	3.18	44	16:24	5
10. Buoy R16A	32 42'24"	117 13'37"	0.24	3.34	45	16:25	5
11. Midway Turns 2 & 3	32 42'33"	117 13'25"	0.41	3.58	43	16:28	5
12. Turn 3 @ G19R18	32 42'51"	117 13'04"	0.73	3.99	73	16:33	3
13. Turn 4	32 43'04"	117 12'15"	0.21	4.72	90	16:48	2
14. Port Turn to PA	32 43'04"	117 12'00"	0.43	4.93	62	16:54	2
15. Precision Anchor	32 43'16"	117 11'33"	0.00	5.36	00	17:07	0

WinCrew and Bridge Model Descriptions

Some of the earliest work with the task networking approach to human performance modeling involved modeling task duration and accuracy (Siegel & Wolf, 1969). Later, the simulation language SAINT (Systems Analysis of Integrated Networks of Tasks) was developed (Pritsker, Wortman, Seum, Chubb, & Seifert, 1974) for task network modeling. Such modeling has been used extensively to evaluate avionics (Kuperman, Hann, & Berisford, 1977) and submarine display systems (Kraiss, 1981). Further development of SAINT led to Micro SAINT, the simulation engine often used in task network modeling. Micro SAINT was the primary building block for a workload modeling developmental effort by the U.S. Army for the new battle tank. This effort was described by Little, et al. (1993) and led to the development of the modeling software program, CREWCUT, for workload estimation of tank crew reduction. As noted in the Introduction, CREWCUT was adapted to the personal computer Windows operating system and renamed WinCrew.

Strong theoretical support for the workload modeling using WinCrew comes from the Multiple Resource Theory (MRT) (Wickens, 1984a). He noted that one of the primary reasons for resource theory development came from the requirement to improve measurement of operator workload. Wickens' MRT of human information processing included several dimensions. Processing stages referred to the encoding of information, followed by central processing of perceptual/cognitive information, and finally by behavioral responses. Processing codes included spatial and verbal, processing modalities included vision and audition, while responses included manual and vocal. When personnel perform tasks they use different resources, such as visual, auditory, cognitive, motor, and speech responses, which are limited. Resource allocation may be required when different tasks require similar resources. When capacity is limited, or allocation of resources is not effective, performance errors may result.

Wickens' MRT has been used extensively in the WinCrew workload modeling software. This software implements an estimation algorithm to provide a moment-to-moment output workload index, by calculating task demands and the resources available to accomplish the tasks (Little, et. al., 1993). In order to improve the accuracy of relating the effects of workload to performance, the model is able to implement workload management strategies which could assess how individuals dynamically change their tasks to cope with overloading workload levels. Example strategies would include (1) all tasks performed regardless of overload, (2) new tasks are not begun or started by another operator, (3) the ongoing task is interrupted, or terminated, or (4) new or ongoing tasks are reallocated to a contingency operator. WinCrew software is in the process of being updated in order to expand the time base to hours, days, years. It will soon be possible to use expressions for workload time bases.

Figure 2 shows the waypoints and major functions performed sequentially by the Bridge Team during the scenario and used in the workload models.

Bridge Model Waypoints and Scenario Functions

1 Point Alpha @ Buoys G5 & R6	**2** Buoys G7 & R8	**3** Buoys G9 & R10	**4** Buoys G11 & R12	**5** Ballast Point (WMSR)
6 Ballast Point (EMSR)	**7** Turn 1 @ G15 & R14	**8** Turn 2 @ G17	**9** Turn 3 @ G19 & R18	**10** Turn 4
11 Precision Anchor				

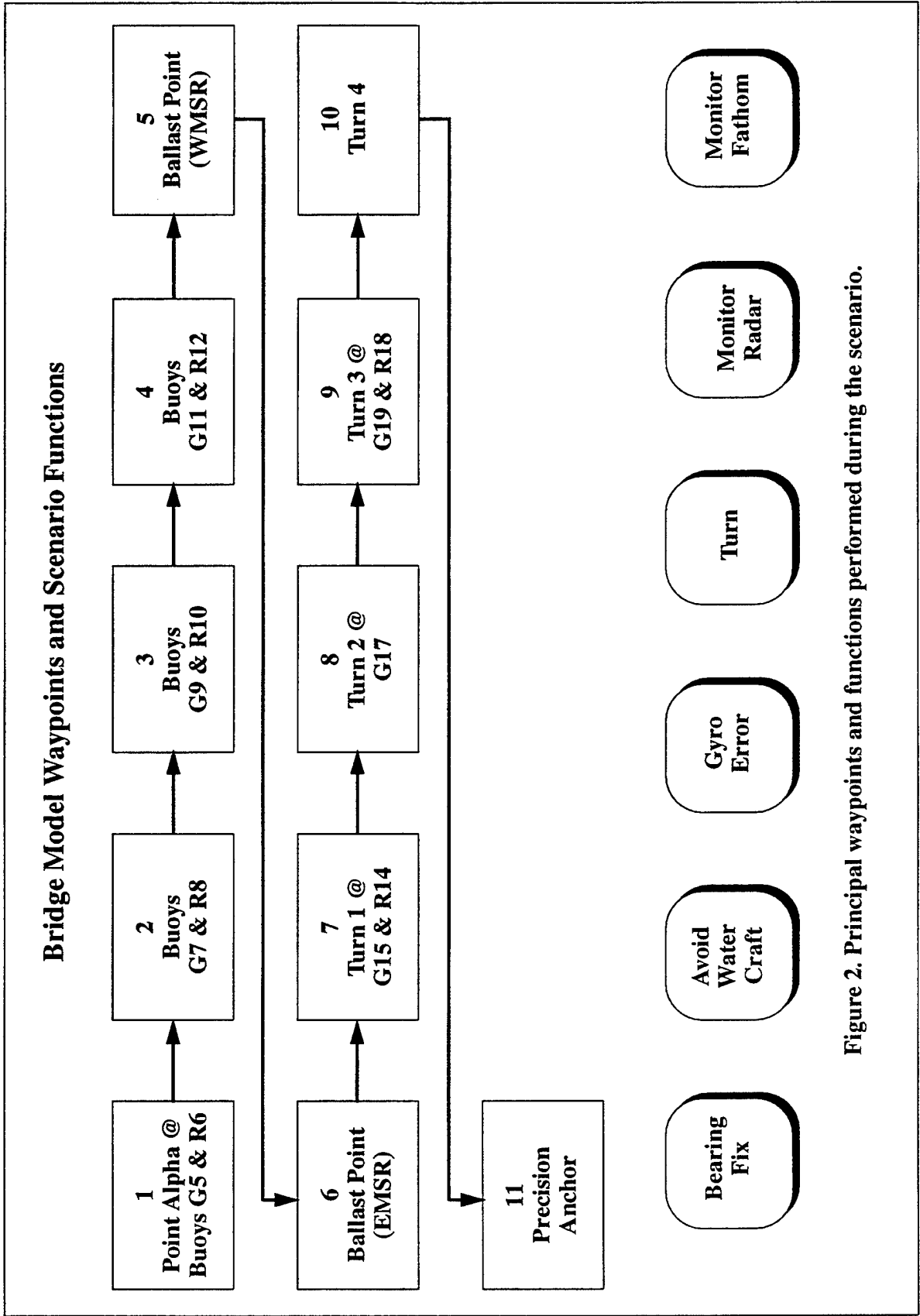Bearing Fix · Avoid Water Craft · Gyro Error · Turn · Monitor Radar · Monitor Fathom

Figure 2. Principal waypoints and functions performed during the scenario.

Specific tasks performed by the individual crew members for each of the functions shown in Figure 2 are presented in Appendix C. Bearing fixes, as well as monitoring the radar and fathometer equipment were performed throughout the scenario. Avoiding the small water craft occurred near Turn 1, while the two gyro error checks were made at waypoint 4 (Buoys G11 and R12), and at waypoint 9, Turn 2.

Even though the candidate workload model of choice for the MAT effort was WinCrew, other commercially available models are available. However, the other models do not provide the micro-level analyses of workload, nor the workload management strategy assessment capability, that WinCrew does.

The scenario information described above was used to define the mission functions. Mission functions were then decomposed into tasks. Task descriptions include the baseline data required for WinCrew applications. In addition to defining the tasks, typical times to perform the task, and other task performance parameters, such as errors, were determined. Operators and automated equipment characteristics were described, which included specifying the moderating parameters, such as fatigue, aptitude, and experience, as well as workload management strategies and workload thresholds of crew members were determined. Crew member resources, such as visual, auditory, speech, cognitive, and motor, required to perform the tasks were identified. Task performer and the operator interfaces required for the task were identified. Crew station design characteristics, as well as crew resources and equipment interface interactions, were identified. Observing equipment dials, which requires visual resources by the operator, would be one example of crew member resource and equipment interface interactions.

Three bridge models were developed for the MAT project to demonstrate workload index changes resulting from current manning and reduced manning requirements. Bridge Model 1 (BM1) reflected a crew of nine members, while Bridge Models 2 (BM2), and Bridge Model 3 (BM3) included reduced manning to three members. BM2 included no additional automated equipment, while BM3 did include such equipment.

Bridge Model 1

Bridge Model 1 approximated the current bridge manning configuration based on information provided in the Preliminary Ship Manpower Document for the DDG-51 Flight IIA (1995) and input from the SMEs. Limitations of WinCrew restricted the number of modeled crew members to 10, which included a required dummy variable. The nine crew members who were modeled included: (1) Officer Of The Deck (OOD), (2) Navigator Evaluator (NAV), (3) Bearing Recorder (BR), (4) Bearing Taker, Port (BTP), (5) Bearing Taker, Starboard (BTS), (6) Navigation Plotter (PLOT), (7) Master Helmsman (MH), (8) Surface Search Radar Operator (SRO), and (9) Fathometer Operator (FO). The specific tasks performed by each of the Bridge Team crew members for each of the principal functions in the model configuration are presented in Appendix C.

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Bridge Model 2

BM2 reduced the bridge manning to three crew members. These included OOD, NAV, and BR. All tasks performed in BM1 with the full bridge crew complement were required to be performed in BM2. Only a basic level of automation was provided. This consisted of an automated harbor display that allowed the BR to perform the tasks of the BTP and BTS. Poor task workload allocation was assumed, which would be reflected in increased workload by the three bridge crew members. OOD was required to perform the tasks of OOD and the MH. NAV did only the tasks of the NAV, while BR performed the tasks of BR, BTP, BTS, PLOT, SRO, FO.

Bridge Model 3

BM3 included the same three bridge crew members modeled as in BM2 (OOD, NAV, BR). However, additional automation equipment was added in this model to assist in reducing workload. This equipment included new gyrocompasses, global positioning system (GPS), integrated bridge display system, and automated logging systems which are currently found in commercial maritime bridge systems. It was expected that with the addition of appropriate automated bridge equipment, there would be a decreased crew member workload similar to that found in BM1, the current fully manned bridge complement.

WinCrew Reports

A variety of reports may be obtained after running WinCrew models. They include: Mission Summary (Mission Performance Time, Time and Cause of Mission Termination), Task Summary (Function and Task Mean Time, Times Executed, Failures), Operator Activity (Chronology of Personnel Activity and Inactivity), Operator Workload (Graphic Display of Workload Profiles), Overload Report (Time of Overload, Identification of Events Surrounding Overload, Workload Threshold, Define Workload Management Strategy), and Task Timeline (Verify Tasks Executed at Specific Time).

Model Workload Data For Current and Reduced Manning

Workload Index data for the Bridge Team in Bridge Models 1, 2, and 3 may be seen in Figures 3-10. Figures 3, 4, and 5 show workload data for the OOD, NAV, and BR in Bridge Model 1, the approximate current configuration of the Bridge Team aboard the DDG-51 Class of ship. As noted earlier, a limit of 9 crew members would be modeled in the current version of WinCrew. Figures 6 and 7 show workload data for the OOD and BR in Bridge Model 2, the reduced crew size, and Figures 8 and 9 show data for the OOD and BR, in Bridge Model 3, also the reduced crew size, but with appropriate automated equipment implemented. Figure 10 shows the workload data for the BR after a 48 hour fatigue moderating condition was implemented during Bridge Model 2.

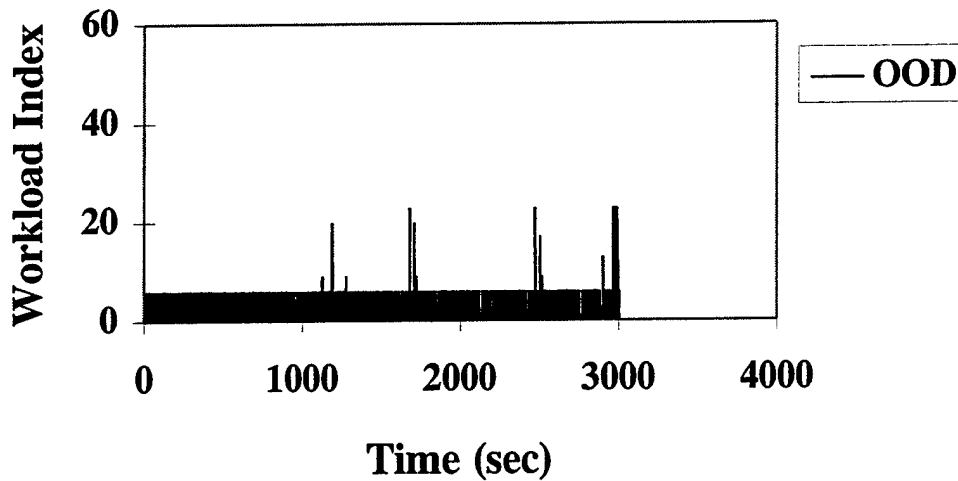**Bridge Model 1: Current Full Complement Bridge Team**

Figure 3. Workload index levels for the OOD during Bridge Model 1.

For most of the "Entry in San Diego Harbor" scenario, the Workload Index (WI) for the OOD in Bridge Model 1 stays below 10, however reaches a maximum of about 20 in four time periods through the scenario. Correspondence of the WI levels may be made with scenario functions being performed (Table 1). These four time periods correspond roughly to the Small Water Craft Crisis activity, between Turns 2 and 3, between Turns 3 and 4, and at the Precision Anchorage.
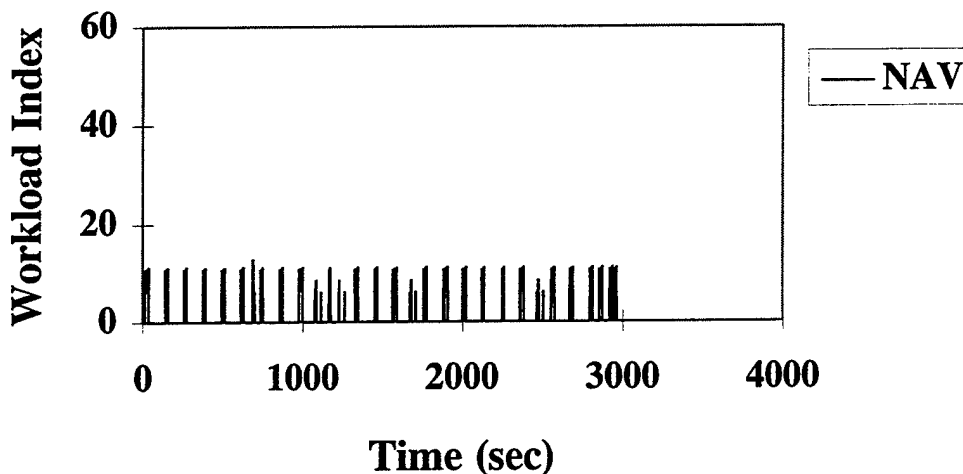

Figure 4. Workload index levels for the NAV during Bridge Model 1.

Unlike for the OOD in Figure 3, the NAV workload index levels remained constant at about 10 throughout the scenario.
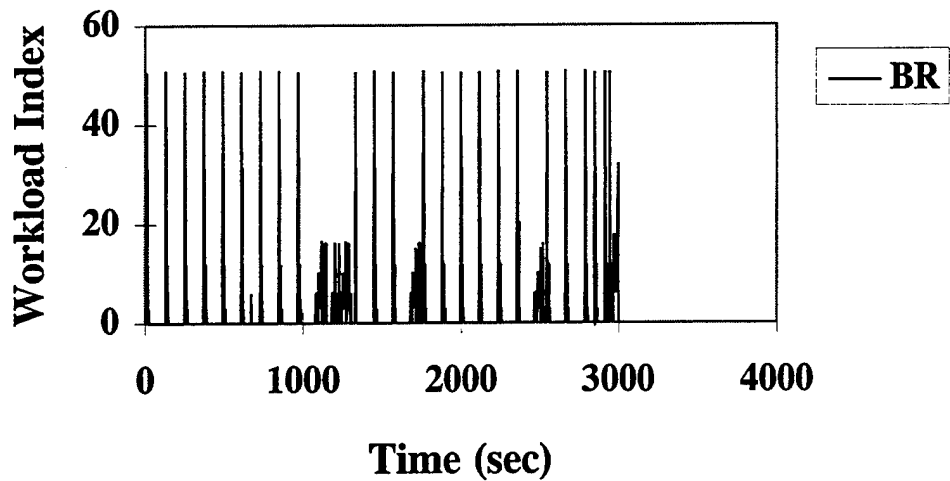
Figure 5. Workload index levels for BR during Bridge Model 1.

It may be seen that the WI for the BR shows maximum levels of greater than 50 throughout the scenario, more than 2.5 times the maximum level for the OOD, and 5 times that for the NAV. The other Bridge Team members included PLOT, BTP, BTS, MH, SRO, and the FO. Maximum WI values for these other members were 30, 16, 16, 25, 10, and 10 respectively.

Bridge Model 2: Reduced Manning Bridge Team

For the Bridge Model 2, the Bridge Team was reduced from nine members to three. An automated harbor display was provided for crew use. The WI level axes for Bridge Model 2 were rescaled in Figures 6 and 7 to 150 from 60 used for Bridge Model 1.
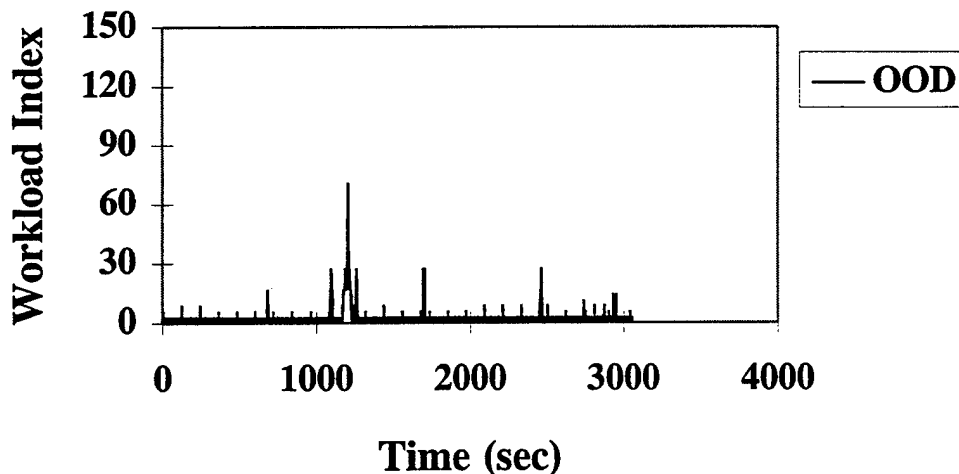
Figure 6. Workload index levels for OOD during Bridge Model 2.

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When the Bridge Team was reduced from nine to three, without additional equipment automation, it was expected that the WI would increase for some members. The WI for the OOD increased substantially from the maximum of about 20 in Bridge Model 1 to 75 in the Bridge Model 2. This maximum WI level corresponded to the activity at Turn 1 and the Small Water Craft Crisis.
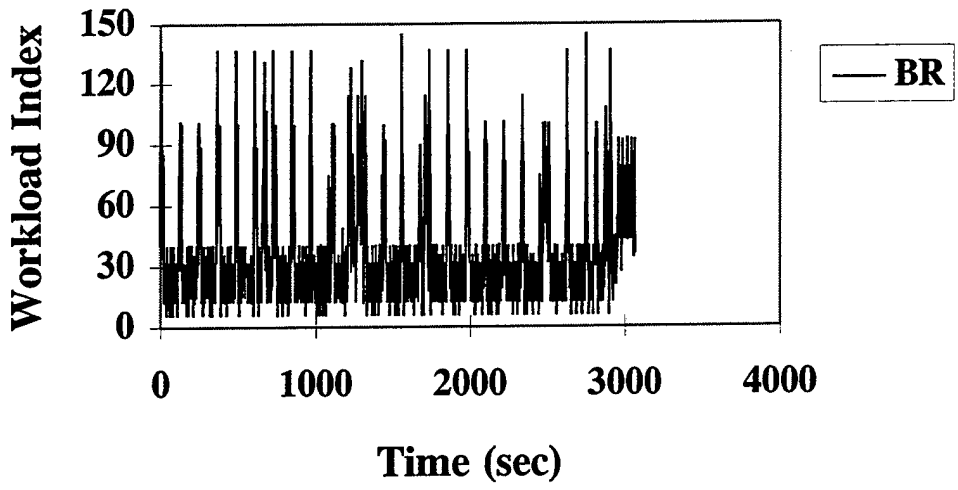
Figure 7. Workload index levels for BR during Bridge Model 2.

The WI levels for the BR during the reduced manning condition increased to more than 130 at many time points throughout the scenario. This increase was by a factor of nearly 3 from that found under the current nine bridge member configuration in Figure 5.

Bridge Model 3: Reduced Manning Bridge Team With Automation

For this model, the Bridge Team was reduce from nine to three individuals, but automated equipment was implemented. As a result, the WI levels for both the OOD and the BR were reduced to below that for the current manning configuration in Bridge Model 1.

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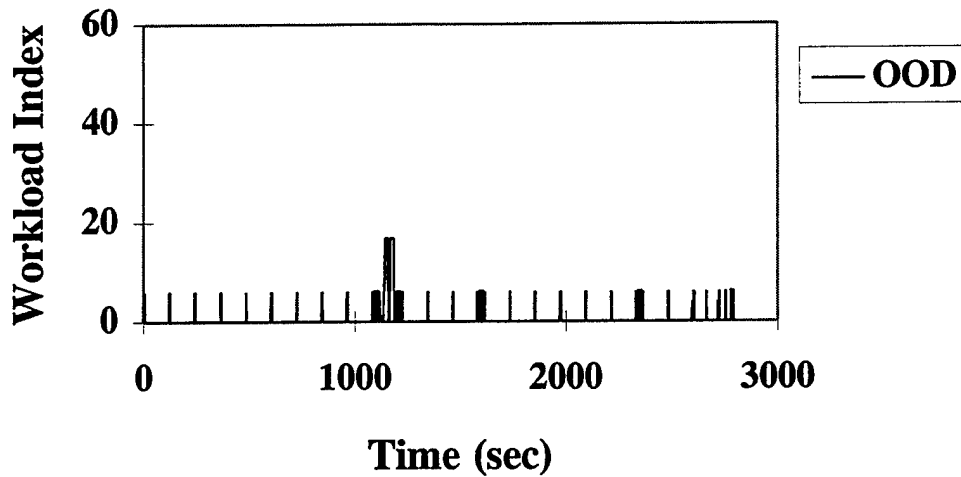
Figure 8. Workload index levels for the OOD during Bridge Model 3.

The maximum level reached for the OOD during the scenario for this model was below 20. This value was obtained during the Turn 1 and Water Craft Crisis period of the scenario.
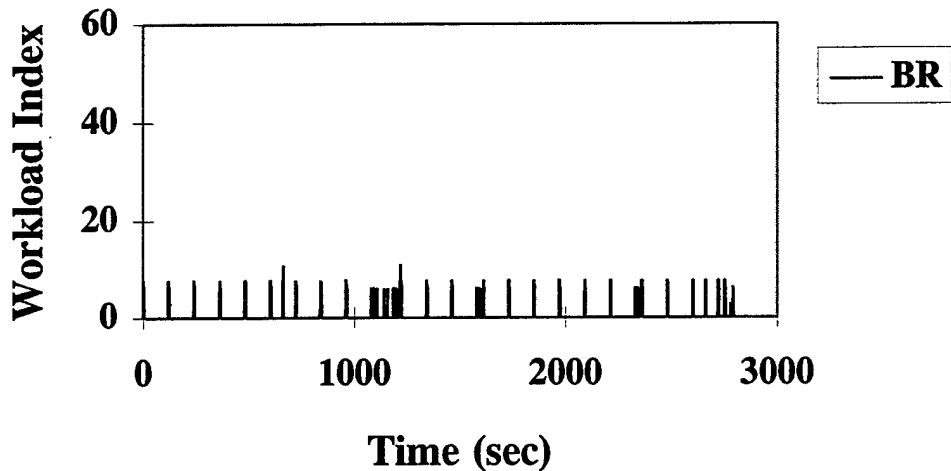
Figure 9. Workload index levels for the BR during Bridge Model 3.

Throughout the Bridge Model 3 scenario, the WI levels for the BR remained at a low 10. These workload levels reflect the off loading of monitoring and other tasks to the automated equipment.

These Bridge Team models were also run using a fatigue moderator. The models were run with all crew members having been subjected to a 48 hour fatigue condition. As expected, fatigue had a substantial adverse affect on most team members. This effect was most

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noticeable for the BR during Bridge Model 2, when the WI increased to nearly 250 near the end of the scenario, as seen in Figure 10. With the exception of this maximum point, the WI level for the BR remained near that of 150 throughout the scenario. These values were similar to the maximum values for the BR in Figure 7.
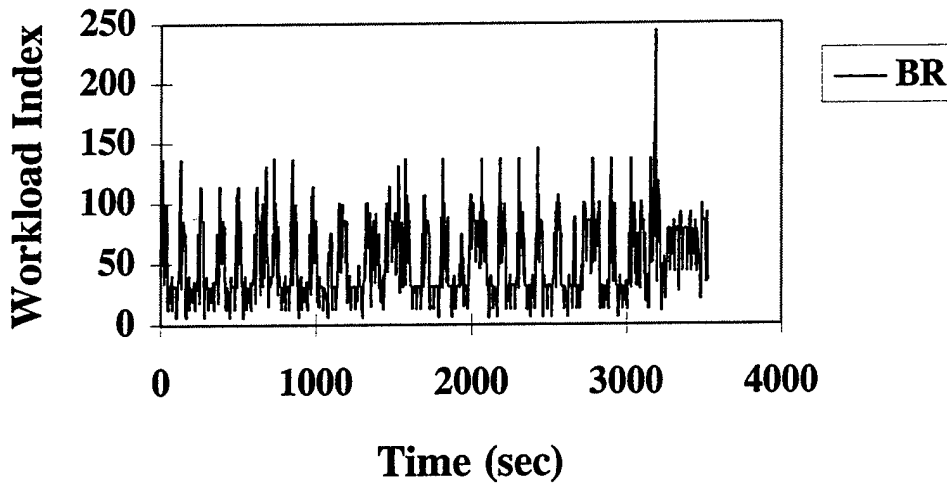
Figure 10. Workload index levels for the BR during Bridge Model 2 after fatigue.

Conclusions and Recommendations

The rapid development of behavioral theory, human performance modeling, and personal computers have provided the needed foundation to assess workload levels of shipboard and shore based Navy Department personnel. Current manning levels and projected manning levels may be assessed at the individual crew member level, and at various time scale resolution, from seconds, as in the current effort to minutes, days and years. Additional moderating variables available in WinCrew, such as experience, fatigue and aptitude would provide increased precision in the workload assessment of Navy personnel. The current Bridge Team modeling effort demonstrates that workload levels may be assessed under current and reduced manning levels, and with or without automated equipment being implemented. Such workload modeling efforts would provide valuable information during current manning configurations, as well as assessment of readiness in operational exercises. Human performance workload modeling would also provide important "what if" personnel information for the design of new ships, and implementation of automating equipment on new ships, such as the SC21, Arsenal Ship, LPD-17, and CVX.

It is recommended that current Navy ship design and building programs, including the Smart Ship Project, adopt modeling and evaluation procedures which include moment-to-moment workload assessment at the individual crew member level. The use of workload modeling has been shown to be feasible, and would make substantial contribution to the objective evaluation of automated equipment implementation and crew member reduction.

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Appendix A

Human Performance Models

Human Performance Models

National Research Council Review of Human Performance Modeling

A major review of quantitative human performance modeling (HPM) was done by the Panel on Human Performance Modeling, National Research Council, over a 4 year period (Baron, Kruser, & Huey, 1990). Focus of the review was on models which were useful for complex system design and development. The Panel assessed the strengths and limitations of existing models, and where and how the models were useful. Four approaches were discussed which included the information processing approach, control-theoretic approach, task network approach, and the knowledge-based systems approach. The models were represented along five dimensions: output versus process orientation, predictive versus descriptive, prescriptive (normative) versus descriptive, top-down versus bottom-up, and single task (limited scope) versus multitask (comprehensive) models.

The report specifies that two different ways in which HPMs are used are to develop and evaluate theories, and design and evaluate systems. HPM for the MAT effort falls under the design and evaluate systems category. Alternative methodologies to modeling include expert opinion, simulation, evaluation of real systems, and laboratory experimentation. The review discussed each of the alternatives to modeling and suggested that benefits to modeling include relative speed over the alternatives to modeling, provide ways of looking at new approaches, more cost effective than simulation or experimentation. Historical development of the models of limited scope and the multitask, macromodels models was provided.

Limited Scope Models

By definition, Limited Scope Models (LSM) tap only a portion of the processing done by personnel. As a result, interest in the Limited Scope Models would be of minimal value for the MAT effort. Some of the models discussed in the review include: Classical Information Theory (Hick, 1952), Discrete Movements (Fitts, 1954), Continuous Tracking (McRuer & Krendal, 1957), Signal Detection Theory (Green & Swets, 1966), and Short-term and Long-term Memory (Norman, 1970). Other LSMs may be found in Boff, Kaufman, and Thomas (1986). Even though LSM may be of limited value for this effort, they may be used in, and provide important information for macromodels.

Multitask Macromodels

Information Processing Models. The example information processing macromodel, which the panel reviewed, was the Human Operator Simulator (HOS). This model was developed for simulating a human-machine system during complex missions. Submodels included Long-term/Short-term Memory Retrieval; Attention and Recall of Current Task Responsibilities; Statement Processing; Information Estimation, Absorption, Calculation; Anatomy Movement; Decision Making; and Accessing Relevant Portions of Procedure. Wherry, (1976); Lane,

Strieb, Glenn, & Wherry, (1981); Meister, (1985); Harris, Glenn, Iavecchis, & Zalkad, (1986) describe the submodels found in HOS. Outputs from the HOS model include among others, time lines for both tasks and the entire simulation, and evaluates human and system performance analyses at several levels of detail.

Primary advantage of HOS is that it simulates complex systems. In addition, HOS has been useful in control/display system design, workstation layout, and task allocation. The principal disadvantage is that it requires input from a development team, as well as not having the capability for evaluating the interaction of various components in human-machine simulations.

Control Theory Models. The panel also reviewed control theory models and knowledge-based models. These approaches are not considered as appropriate as the information processing or task network models for the MAT effort. Primary emphasis within control theory modeling initially was on continuous manual control based on time-domain procedures (Baron & Levison, 1980) and frequency-domain procedures (McRuer & Krendel, 1974). Time-domain models later included applications of failure detection (Gai & Curry, 1976), monitoring (Kleinman & Curry, 1977), and decision making (Pattipati, Ephrath, & Kleinman, 1980). The main disadvantage to control theory modeling has been the requirement of great sophistication in mathematics and control theory.

Knowledge Based Models. The knowledge-based models (KBM) are considered to be different from typical HP Modeling, which usually assess and/or predict individual performance under specific assumptions. KBM approaches address processes during problem solving, which were developed from early computer simulation (Newell, Shaw, & Simon, 1958; Newell & Simon, 1972). Their logical argument followed from the fact that computer programs manipulate symbols, and human thought manipulates symbols, therefore, human thought could be modeled by computer programs. Application of KBM to complex system failures (Rouse, 1983) and problem solving in complex systems (Rasmussen, 1986), and personnel training for complex systems (Anderson, Boyle, & Reiser, 1985; Rouse, Geddes, & Curry, 1987) have been made. The primary advantage of the KBM approach is that of determining how individuals use specific knowledge in the solution to complex problems. A disadvantages of this approach includes their not being used to quantitatively predict performance, models are expensive to construct, and difficult to evaluate.

Task Network Models. The task network (TN) approach assumes that an operator performs one or more tasks and follows procedures to accomplish a function. The TN approach has been the one of choice to assess many real-world workload problems for many years. Specific task variables include time for completion, error rates, etc. Interaction of operators, tasks and environmental conditions, including equipment interfaces can be evaluated effectively with TN models. Operator workload may be quantified and reallocated as a function of number and kind of tasks, or their interaction. Some of the advantages of the TN approach include: generality, encouraging top-down modeling, formulate models at various levels of detail. Disadvantages of the TN model approach include: the assumption that task

attributes are additive, interacting modules may make checkout and validation difficult, and the identification and development of procedures and tasks may not be unique.

NAS HP Modeling Conclusions

The NRC Panel review concluded that the approaches are converging, few if any models had traditional full validation, none dealt with operator discretion and cognitive behavior, individual differences were ignored, and no single approach will dominate.

Nuclear Weapons Security Behavioral Model

Another example of a human performance macromodel was the Nuclear Weapons Security Behavioral Model (BEMOD) developed under contract from the Navy Personnel Research and Development Center, San Diego to Mission Research Corporation (MRC), Santa Barbara, California during the late 1970s and early 1980s. Stinson (1979a,b) provided the rationale and background for the Shipboard Nuclear Weapons Security Program, including BEMOD. The current BEMOD overview used several sources (Ewing, 1982a,b; Ewing 1983a,b,c; Ewing & Caccamise, 1983a,b), but depended most heavily on Ewing's MRC report (Ewing, 1990a,b,c) for updated algorithms and detailed discussions. BEMOD supported generic nuclear weapons security models, which were used to simulate candidate security systems and elements. Such simulations were part of an overall upgrade to shipboard security of nuclear weapons and weapon materials. BEMOD supported primarily the Safeguards Network Analysis Procedure (SNAP) simulation (Miner & Grant, 1978; Spinosa & Grant, 1979). SNAP modeled scenarios for the interaction of two groups of personnel, guards and adversaries. Two additional simulations included Safeguards Automated Facility Evaluation (SAFE), which determined the most likely routes taken during a well planned attack, and Matrix Analysis of the Insider Threat (MAIT), which evaluated nuclear weapon systems procedures against unauthorized access to secured areas.

BEMOD was written in FORTRAN and provided the critical human sensory, perceptual, decision making, and fatigue input to the SNAP scenario simulations. The algorithms used in BEMOD were well defined and described. Numerous human micromodels were grouped under the headings of Information Acquisition-Audition and Speech, Information Acquisition-Visual Target Acquisition, Information Acquisition-Communication, Memory, Task Performance, Task Performance-Fatigue, and Decision Making. The Information Acquisition-Audition and Speech category included the four micromodels of Detection and Recognition of Audio Signals, Sound Energy Propagation, Establishing Vocal Level, and Orientation to Sound Source. Six micromodels were included within the Information Acquisition-Visual Target Acquisition category: Establishing Fixation Probability, Visual Acuity and Threshold Detection, Visual Recognition, Geometric Effects on the Visual Process, Visual Adaptation, and Vigilance. No additional micromodels were included with Information Acquisition-Communication. Three micromodels within the Memory category included Memory Organization, Memory Item Recall and Storage, and Information Encoding. The three micromodels within the Task Performance category included Mental Demand, Dexterity, and Physical Effort. Four micromodels were included within Task Performance-Fatigue, denoted

as Maximum Energy Expenditure Rate and Actual Fatigue, Thermal Stress, Heart Rate, and Subjective Fatigue. The Decision Making model included Standard Operating Procedure Rules. Each of the models will be reviewed briefly.

Information Acquisition-Audition and Speech

The audition modeling algorithm was based on the Articulation Index (AI). The AI was developed for measuring the intelligibility of speech, and estimated the relationship of signal energy to background noise. The traditional sound level measure, based on dB units, was used. For the auditory detection-recognition model, the AI was used for sounds as well as for speech because in operational settings, signals and noise generally have broad spectra. The AI approximated the complex signals and noise spectra found in operational environments. Phonetically balanced words and nonsense syllables were used to generate curves relating the AI to percent of information understood. Assuming detection, curves were used to test the probability of recognizing speech and sound. Sound energy propagation was dealt with in a traditional way for both above and below the ship's deck. The propagation was taken as the inverse of the distance squared from the source relative to the referenced sound level. Vocal level and the probability of the observer orientating to the sound source were also computed in these audition and speech micromodels.

Information Acquisition-Visual Target Acquisition

The models for visual targets included estimating probabilities for fixation, detection and recognition. Factors affecting fixation included foveal acuity level, threshold contrast ratios, target eccentricity, and target angular motion. Factors associated with probability of detection included visual acuity, luminance, visual adaptation, source distance, surface reflectivity, and eye resolution. Vigilance was only briefly discussed under visual target acquisition, and no algorithm was provided. Mention was made of the complexity of vigilance and it's relationship to the individual differences of personnel, and complexity and intensity of the background environment. Other aspects of vigilance, such as arousal level, were developed under the decision making model category.

Information Acquisition-Communication

The model developed here was not based on operational data, but represented an *ad hoc* construct based on experience, which MRC developed over many years of security work. Components of the communication model included decision to communicate, message formulation, attention signal, signal acknowledgment if two-way communication was involved, synchronized send-receive between speaker and listener, and memory of the message communicated and received. Navy personnel data such as the verbal composite score from the Armed Forces Vocational Aptitude Battery (ASVAB) were used along with fitness report information to develop a verbal abilities factor for communication. Message formulation was determined by stress level (discrete levels of low, moderate, high) and verbal ability. Stress

level limits the number of message elements. Memory likewise played a major role in message communication.

Memory

Several constructs of current memory theory were used in the memory model. These included information acquisition and storage, memory item recall, and memory priming. Memory has been modeled as two linked lists of items, a short term memory (STM), and a second long term memory (LTM). Items included in the LTM list were security standard operating procedures (SOP), common sense rules of behavior, and prior knowledge. Each item was equally accessible. Items in the STM list were generated during scenario execution and included information from direct experience, communication, decisions, and actions taken. There were six information dimensions which could be stored with each memory item and included "who," "what," "where," "when," "why," and "how." Each of the previous dimensions were separated into a course and fine level of information storage. Individuals with greater expertise would be able to "chunk" the information more effectively than novice individuals. Novices would store information at the course level, whereas experienced individuals would have greater access to more detailed information, in part by having increased probability of access during information storage in LTM. Memory recall depended on successfully searching STM. If this search was unsuccessful, BEMOD developed a probability of recall attempt, which was dependent on arousal level. Arousal affected not only storage and recall, but also influenced mental capacity in the model. Allocation of resources across tasks depended on job motivation, which was accomplished in the Task Performance model noted below. Six factors influenced arousal in the Decision Making model covered below. These included perceived threat level, job experience, training, subjective fatigue, event rate, and the rationality-under-stress component from Navy security personnel fitness reports. Encoding of information was related to equivalent Navy experience. Such experience was modeled to include job motivation, composite Academic Achievement percentile fraction of the Armed Forces Vocational Aptitude Battery (ASVAB), time in training in weeks, elapsed time since training in months, years of Navy service, years of service in grade, and years of service in billet.

Task Performance

A functional task analysis was used by BEMOD to determine job performance. Three performance dimensions used to model tasks included mental demand required, dexterity, and physical effort. Simplification of the task analyses was determined from extensive experience that MRC had in security scenario analyses. Such analyses showed that security confrontation outcomes were determined primarily by timing of interactions (timeline analyses). The three dimensions noted above affected task duration, therefore the individual's scenario timelines.

Mental Demand. The value of mental demand was set to high, moderate, or low. Allocation of mental demand and mental capacity to the attention demanding tasks determined task duration. Completed tasks were modeled as a function of total accumulated attention,

which was the summation of time spent on task and mental capacity assigned. The basic assumption of direct relationship between high motivation and attention was followed. Motivation was constructed primarily around job motivation. Job motivation was considered as a personality factor, but was based on Navy fitness report items such as appearance, adaptability, behavioral infractions, and conduct.

Dexterity. This dimension was modeled as high, average, or low levels based on generalized frequency of manipulation.

Physical Effort. As with dexterity, this dimension was quantified as high, average, or low. Physical effort was modeled such that each task would produce subjective fatigue as a function of time on task, and as such would influence decisions about starting, continuing, discontinuing, and resuming activities.

Task Performance-Fatigue

In addition to modeling constructs, data from Olympic running athletes, along with motivation and stress information were combined into a subjective fatigue factor. The latter factor was used in decisions which involved rate of work. For this Task Performance-Fatigue (TP-F) model, functional estimates of work rate included two values, the discretionary hard work limit which was noted as 2000 kcal/day, and the hard work rate noted as 6.5 kcal/min. A typical diet was taken as 2500-3500 kcal/day for the BEMOD actors. The basal metabolic rate (BMR) was taken as 1.2 kcal/min. Examples of other fixed energy rates were 3.5 kcal/min. for light work, 7.0 kcal/min. for extended fire fight (>10 min.), and 13.0 for a short fire fight (<1 min.), or a 20 second sprint by a trained athlete. Maximum energy expenditure rates as a function of time were scaled to average Navy Department personnel, which allowed the BEMOD actors to carry heavy objects and move from deck to deck onboard ships. Maximum loads carried by the actors were limited to less than 50 percent of body weight. A thermal stress micromodel was assessed under the Task Performance-Fatigue model. Factors taken into account in this micromodel were environmental temperature, latent heat of water vaporization, body surface area, body temperature, and basic water loss rate. Heart rate (HR) and blood pressure (BP) were also computed under this model. Heart rate and blood pressure were related to work rate in the TP-F model. Exhaustion was able to be modeled using HR and BP. The subjective fatigue model included the stress level (high, average, low), motivation factor (derived from job motivation information), a physical conditioning factor, and maximum pulse rate.

Decision Making

The BEMOD Decision Making (DM) model used Bayesian weighted-utility models. Individuals ranked alternative choices for making a decision based on a subjective likelihood of outcome. For the application of BEMOD to shipboard security scenarios, it was assumed that two types of decisions occurred, the application of an operational rule (or common sense rule), or making a reaction response to situations not covered by the operational rule. Template

matching of the situation with response rules (standard operating procedures) occurred, and if criteria were met, action was taken. The reaction response decisions used the Bayesian utility, or risk, analysis algorithm. Other factors taken into account in the DM model included stress, alertness, memory storage, and mental capacity.

Task Priority and Scenario Action Flow

The four variables which influenced the flow of the scenario actions included arousal level, perceived threat, subjective fatigue, and mental workload. Setting arousal was dependent on the factors of event rate, effective experience, rationality-under-stress (determined from Navy security personnel fitness reports), and subjective fatigue. Perceived threat was determined from the probabilities of threats to one's self and threat to the overall mission.

A conclusion reached in this review of BEMOD was that the use of relevant Navy personnel data, and the algorithms in BEMOD briefly described above would contribute substantially to the modeling effort of the Manpower Assessment Technologies project.

The Card, Moran, and Newell Model of Human Performance

Card, Moran, and Newell (1983; 1986) have developed a macromodel of human performance for use in engineering design problems, called the model human processor (MHP). In addition to developing their model, the authors provided numerous examples of how to use the model and showed how engineering predictions could be made of human performance. The MHP includes interconnecting memories and processors, and principles of operation. Memory and processor components included three subsystems, the perceptual system, cognitive system, and the motor system. The perceptual system included the visual and auditory sensory system, and associated memory. The perceptual system also performs the symbolic coding of the visual and auditory information for later use by the cognitive system. The cognitive system combines the "sensory image stores" in working memory with other information already held in "long term memory" for decision making and later responses made by the motor system. Opposing voluntary muscles are the primary components of the motor system, and they suggest that for machinery operators, the two most important muscle systems are the arm-hand-finger system and the head-eye system. They specify the three parameters of memory as storage capacity, decay constant, and visual and auditory code type, while the single parameter of a processor was cycle time.

The authors cite an extensive literature to provide quantitative data for describing the perceptual, cognitive and motor systems. Description of the MHP was detailed. The level of detail for the model and examples, and the apparent lack of off-the-shelf modeling capability suggested that other macromodels would be more easily applied to the MAT modeling effort.

Appendix B

Additional Relevant Literature

Additional Relevant Literature

Two categories of literature were examined, which provided additional information on modeling and reduced manning issues. The categories include: Personnel Assessment Technologies and Personnel Cost Models. In the first category are included the topic areas of attention, arousal and vigilance; signal detection, sensory, perceptual and cognitive processing, including brain and behavior relationships; personnel selection and classification; and advanced technologies for personnel assessment.

Personnel Assessment Technologies and Modeling

Technologies for personnel assessment: Albus (1981); Baecker and Buxton (1987a,b); Ball, Evans, and Dennis (1994); Barnes (1979 & 1981); Baron and Kleinman (1969); Bekey and Neal (1968); Booth (1989); Boudreau (1989); Bradford (1974); Broadbent (1971); Carbonell, Ward, and Senders (1968); Christ (1993); Coles, Donchin, & Porges (1986); Commons, Nevin, and Davison (1991); Cornsweet (1970); Davies and Tune (1969); Druckman and Swets (1988); Druckman and Lacey (1989); Dunnette (1966); Edelman, Gall, and Cowan (1990); Egan (1975); Evans and Mulholland (1969); Eysenck (1982); Eysenck and Eysenck (1985); Fisher, Monty, and Senders, (1981); Gale and Edwards (1983a,b,c); Gazzaniga (1984); Gevins, Cutillo, Illes, Bressler, and Brickett, (1990); Ghiselli, (1966); Graham, (1965); Greenfield and Sternbach (1972); Gray (1987); Green, Wing, and Wigdor (1988); Grossberg (1987a,b); Harris, McCloy, Dempsey, DiFazio and Hogan (1994); Huey and Wickens (1993); Hunt (1987); Hunt and Hertzog (1981); Just and Carpenter (1992); Kanfer and Ackerman (1989); Kennington, Mohammadi, and Mohammed (1993); Klahr and Kotovsky (1989); Knoop (1978); Krass (1987); Lambert (1987); Lewis and Sorenson (1989); Liu and Wickens (1994); Luce (1986); Luria (1980); Mackie (1977); McRuer and Krendel (1974); Meister (1985); Meyer, Kieras, Lauber, Schumacher, Glass, Zurbriggen, Gmeindl, and Apfelblat (1995); Muir (1994); Nakada (1984); Nakada, Milczewsky, and Wax (1989); Nickerson (1980); Parasuraman and Davies (1984); Pfeiffer, Siegel, Taylor, and Shuler (1979); Pompeiano & Marsan (1981); Rabbit & Dornic (1975); Reynolds & Brown (1984); Reynolds and Willson (1985); Roth, Woods, and Pople (1992); Scheilbel and Wechsler (1990); Schneider and Detweiler (1988); Selfridge, Rissland, and Arbib (1984); Shackel (1991); Shoecraft (1985); Siegel and Wolf (1969); Singleton, Fox, and Whitfield (1971); Swets (1973); Thatcher and John (1977); Thompson (1967); Thorndike (1982); Tilley (1969); Tribus (1969); Turner, Sherwood, and Light (1992); Weinberger, McGaugh, and Lynch (1985); Wickens, (1984b); Wigdor and Green (1986); Winfree (1987); Wright (1984); and Wright (1974).

Personnel Cost Models

Personnel cost, and cost models, also include cost justification: Alexander and Getty (1995); Eskew, Berterman, Smith, Noah, and Breauz (1978); Green (1991); Kleinman and Curry (1977); Koehler (1979a,b); Koehler (1980a,b); Koehler and Turney (1981); Martin,

Koehler, Mairs, and Hogan (1977); Moor and Andrews (1992); Smith, Eichers, Rose, and Rostker (1994); Stone, Rettenmaier, Saving, and Looper (1989); and Thompson (1980).

Appendix C

Bridge Model 1 Functions and Tasks

Bridge Model 1 Functions and Tasks

The following Bridge Team workload model functions and tasks were provided by Micro Analysis and Design, Inc., Boulder, Colorado from the scenario input provided by this Center.

Function Name	Task Name
Point Alpha	START
Point Alpha	Pt Loma Lighthouse Bearing
Point Alpha	Tactical Branch
Buoys G7 & R8	START
Buoys G7 & R8	Zulu Bearing
Buoys G7 & R8	Tactical Branch
Buoys G9 & R10	START
Buoys G9 & R10	Zuniga Point Bearing
Buoys G9 & R10	Tactical Branch
Buoys G11 & R12	START
Buoys G11 & R12	NIMW Bearing
Pre Ballast	Gyro Error Check
Pre Ballast	Finish Check
Ballast Point	START
Ballast Point	Shelter Island Light Bearing
Ballast Point	Tactical Branch
Turn 1	Perform Turn 1
Turn 1	Small Craft Obstacle
Turn 1	Obstacle Passed
Turn 2	Perform Turn 2
Turn 2	Gyro Check 2
Turn 2	Shore Tower Bearing
Turn 2	Tactical Branch
Turn 3	START
Turn 3	Shore Tower Bearing
Turn 3	Tactical Branch
Bearing Fix	'Standby'
Bearing Fix	Locate Nav Aid (BTP)
Bearing Fix	Locate Nav Aid (BTS)
Bearing Fix	Rejoin 1
Bearing Fix	Reading Done Dummy
Bearing Fix	Train Alidade (BTP)
Bearing Fix	Train Alidade (BTS)
Bearing Fix	Communicate (BTP)
Bearing Fix	Communicate (BTS)
Bearing Fix	'Mark' (BR)

Bearing Fix	Give Readings (BTP)
Bearing Fix	Give Readings (BTS)
Bearing Fix	Hear Readings (BR)
Bearing Fix	Record Data in Log (BR)
Bearing Fix	Repeat Readings (BR)
Bearing Fix	Done
Bearing Fix	Look at Chart (BR)
Bearing Fix	Plot Bearing (PLOT)
Bearing Fix	Determine New Nav Aids (PLOT)
Bearing Fix	Look at Chart (NAV)
Bearing Fix	Alert BTs to Next Nav Aid (PLOT)
Bearing Fix	Look Out Window (NAV)
Bearing Fix	Hear Next Nav Aid (BTP)
Bearing Fix	Hear Next Nav Aid (BTS)
Bearing Fix	Complete Course Navigation (PLOT)
Bearing Fix	Evaluate Situation (NAV)
Bearing Fix	Look Ahead & Communicate (BTP)
Bearing Fix	Look Ahead & Communicate (BTS)
Bearing Fix	Compare Old DR to Current (PLOT)
Bearing Fix	Report Course Obstacle (NAV)
Bearing Fix	Tell BR when Nav Aid Visible (BTP)
Bearing Fix	Tell BR when Nav Aid Visible (BTS)
Bearing Fix	Redo Ship's Track (PLOT)
Bearing Fix	Hear Course Correction (OOD)
Bearing Fix	Hear BTs (BR)
Bearing Fix	Initiate Corrective Action (none)
Bearing Fix	Hear Bearing (PLOT)
Bearing Fix	Start Record Dummy
Bearing Fix	Repeat Done Dummy
Bearing Fix	Start Repeat Dummy
Avoid Obstacle	Issue Course Correction Order (OOD)
Avoid Obstacle	Hear Course Change Order (BR)
Avoid Obstacle	Hear Course Change Order (BTP)
Avoid Obstacle	Hear Course Change Order (BTS)
Avoid Obstacle	Hear Course Correction Order (MH)
Avoid Obstacle	Report Course Change (BR)
Avoid Obstacle	Observe Obstacle (BTP)
Avoid Obstacle	Observe Obstacle (BTS)
Avoid Obstacle	Complete Turn (MH)
Avoid Obstacle	Relay New Heading (MH)
Avoid Obstacle	Hear New Heading (OOD)
Avoid Obstacle	Hear New Heading (PLOT)
Avoid Obstacle	Plot New Heading (PLOT)
Avoid Obstacle	Hear New Heading (BR)
Avoid Obstacle	Record New Course (BR)

Avoid Obstacle	Obstacle Bypassed (BTP)
Avoid Obstacle	Hear Obstacle Bypassed (OOD)
Avoid Obstacle	Correct Course Order (OOD)
Avoid Obstacle	Hear New Course Order (MH)
Avoid Obstacle	Complete Turn (MH)
Avoid Obstacle	Relay New Heading (MH)
Avoid Obstacle	Hear New Heading (OOD)
Avoid Obstacle	Hear New Heading (PLOT)
Avoid Obstacle	Plot New Heading (PLOT)
Avoid Obstacle	Hear New Heading (BR)
Avoid Obstacle	Record New Track (BR)
Gyro Error	START
Gyro Error	Search for Gyro Check Items (BTP)
Gyro Error	Look for Gyro Check Items (BTS)
Gyro Error	Prepare BR for GC (BTS)
Gyro Error	'Range Up' (BTS)
Gyro Error	Wait for Points to Line Up (BTS)
Gyro Error	Hear 'Range Up' (PLOT)
Gyro Error	Determine Bearing (PLOT)
Gyro Error	Mark Range and Bearing (BTS)
Gyro Error	Hear Range (BR)
Gyro Error	Correction Needed?
Gyro Error	Mark & Report Gyro Correction (PLOT)
Gyro Error	Hear & Evaluate Gyro Correction
Gyro Error	Relay Correction (NAV)
Gyro Error	Hear Gyro Correction (OOD)
Gyro Error	No Gyro Correction Needed
Turn	Call for Constant Bearings (PLOT)
Turn	Hear Call (BR)
Turn	Relay Order to BTS (BR)
Turn	Hear Turn Order (BTS)
Turn	Hear Call (NAV)
Turn	Advise OOD of New Bearing (NAV)
Turn	Hear New Course (OOD)
Turn	Hear Turn Order (BTP)
Turn	Perform Constant Fixes (BTP)
Turn	Pan with Alidade (BTS)
Turn	Report Bearing (BTS)
Turn	Hear Bearing (BR)
Turn	Repeat Bearing (BR)
Turn	Hear Bearing (PLOT)
Turn	'Mark the Turn' (PLOT)
Turn	Stop Calling Bearings (BTS)
Turn	Hear Mark (NAV)
Turn	Hear Mark (BR)

Turn	'Mark the Turn' (NAV)
Turn	'Relay Your Mark' (BR)
Turn	Hear Mark (OOD)
Turn	Make Turn Order (OOD)
Turn	Hear Turn Order (MH)
Turn	Complete Turn (MH)
Turn	Relay New Heading (MH)
Turn	Hear New Heading (OOD)
Turn	Hear New Heading (PLOT)
Turn	Hear New Heading (BR)
Turn	Plot New Heading (PLOT)
Turn	Record New Heading (BR)
Precision Anchor	START
Precision Anchor	Unnamed
Monitor Radar	Monitor Surface Radar (SSRO)
Monitor Radar	New Contact?
Monitor Radar	Detect Contact (SSRO)
Monitor Radar	Id New Contact (SSRO)
Monitor Radar	Evaluate New Contact (SSRO)
Monitor Radar	Report Contact (SSRO)
Monitor Radar	Hear Contact Report (NAV)
Turn 4	START
Turn 4	Shore Tower Bearing
Turn 4	Tactical Branch
Anchor	Get Head Bearing
Anchor	Order One Min. Bearing Fixes (OOD)
Anchor	Order 30 Sec. Bearing Fixes (OOD)
Anchor	Order Backing (OOD)
Anchor	Hear Backing (BTS)
Anchor	Hear Backing (BTP)
Anchor	Report Bearing (BTP)
Anchor	Report Bearing (BTS)
Anchor	Hear Bearing (BR)
Anchor	Relay Bearing (BR)
Anchor	One Minute Fixes
Anchor	30 Second Fixes
Anchor	Hear Bearing (OOD)
Anchor	Anchor Drop Area?
Anchor	'Let Go Anchor' (OOD)
Anchor	Hear 'Let Go Anchor' (BR)
Anchor	'Mark a Fix' (BR)
Anchor	Report Bearing (BTP)
Anchor	Report Bearing (BTS)
Anchor	Hear Bearing (BR)
Anchor	Relay Bearings (BR)

Anchor	Scrub Charts (PLOT)
Anchor	Plot Fix (PLOT)
Anchor	Extend Line Radius (PLOT)
Anchor	Draw Drag Circle (PLOT)
Anchor	Hear Bearings (OOD)
Anchor	Hear 'Mark..' (BTP)
Anchor	Hear 'Mark..' (BTS)
Anchor	Hear 'Mark...' (PLOT)
Anchor	Mark Compass (MH)
Anchor	Hear Backing (MH)
Anchor	Order to Engine Room (MH)
Monitor Fathometer	Monitor Fathometer
Monitor Fathometer	Take Fathometer Reading
Monitor Fathometer	Report FO Reading to Bridge
Monitor Fathometer	Hear Fathometer Reading

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