SYSTEM DEVELOPMENT OF A SHIP HANDLING SIMULATOR

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The U. S. Merchant Fleet is an essential element of our commerce and defense. American Flag vessels operate under very stringent regulations governing vessel safety and the protection of life at sea. However, collisions and groundings involve a significant number of vessels each year. This constitutes a problem which warrants an organized effort toward solution.

Research to identify causes and define solutions to problems such as collisions and groundings is a natural application for simulation. The conditions of an experiment can be controlled, and results observed more accurately than if actual vessels were used. Study variables can be changed over wide ranges. New equipments and procedures can be investigated more easily and quickly in a simulator than in the real world. Potential risk situations can be investigated without endangering either the "own ship" or other traffic. Also, the cost of simulation is generally much less than the cost of a comparable study using full-scale ships in an actual harbor or seaway.

With this research in mind, the U. S. Maritime Administration in mid-1971 authorized Sperry Systems Management, a division of Sperry Rand Corporation, to conduct studies toward the development of a marine research simulator. These studies affirmed the concept of simulation based research and defined the overall configuration. Hardware and software development was authorized in mid-1973. The resulting system was delivered by Sperry in December 1975, and put in operation for the National Maritime Research Center of the Maritime Administration.

The Computer Aided Operations Research Facility (CAORF), is designed to conduct navigational and ship handling experiments to enhance the safety, productivity, and competitiveness of the American Merchant Marine. Some of the system engineering aspects of CAORF are covered in this paper. System requirements are considered first, followed by discussions of the functions of the major subsystems and the overall configuration, and how each contributes to fulfillment of the system requirements.

SYSTEM REQUIREMENTS

The system requirements for a research simulator are somewhat broader than the requirements for a simulator which is used primarily for training. Much of the investigation of the causes of collisons and groundings, for example, must focus on the performance of the crew on the bridge and the man-machine interface at the bridge, under high-stress maritime situations. The research simulator must:

1) Simulate each of the operational and environmental factors which significantly affect the performance of the bridge crew

2) Simulate each of these factors with *sufficient realism to produce valid* results

3) Provide flexibility to permit rapid changes in these factors

4) Include the capability for recording and storing information from each experiment for study and analysis.

There are other requirements; however, these are among the most critical.

Referring to the first of these requirements, the important elements of maritime operation which affect the bridge crew, and which should be simulated realistically, include:

- Instrumentation and the layout of the bridge
- Ship's performance and "feel;" i.e., its propulsion and steering dynamics, and hydrodynamic characteristics
- Configuration of the harbor or seaway in which the ship is operating
- Navigation aids, cultural features, and important landmarks which are visible from the bridge
- Other ship traffic; types of ships, courses, maneuvers
- Communications from the "own ship's" engine room, other ship traffic, and shore facilities
- Visibility; fog, haze, day, or night
- Unexpected breakdowns of ship equipment; propulsion, steering, and electric power.
- Color of objects in the scene.

Referring to the second requirement, realism of simulation requires that the bridge crew be surrounded by realistic equipment, and that the sights and sounds of the real world situation be adequately reproduced. For a research simulator which focuses on crew performance, realism also requires that the "mood" or atmosphere of the real world situation be established and maintained throughout the simulation. For example, insofar as is feasible, the approaches to the simulation area should have a maritime decor similar to a ship's passageways. Once the simulation is started, it should not be interrupted by external disturbances nor breakdowns of simulator equipment. Apart from the impact of availability on simulator operating economics, high availability is an essential requirement for adequate realism.

The third requirement implies flexibility at several levels. During an experiment, for example, the simulator should be capable of changes in weather and visibility, and in the number and types of traffic ships. It should be possible to make changes such as bridge arrangement, dynamic characteristics of "own ship," configuration of navigation aids, or minor cultural features, between parts of an experiment. Major changes, in harbor configuration, or the experiment gaming area, should be possible in a reasonably short time between experiments. Over a long period of time, it should be possible to add new equipments and capabilities to the simulator in order to permit evaluation of proposed advances in the state-of-the-art.

To meet the fourth requirement, the simulator system should include, in addition to conventional recording and printout or plotting capabilities, some means for recreating and observing portions of the experiment activities for detailed study and analysis.

The configuration and operation of the major CAORF elements are described next to show how CAORF meets the four basic requirements above.

WHEELHOUSE AND BRIDGE

The bridge crew operates in a full-scale "own ship's" wheelhouse, fully equipped with contemporary instrumentation and controls. The engine order telegraph, steering stand, and other bridge instruments and controls are current commercial models selected after a survey, to identify those types which are in widespread use on U. S. Flag vessels. Standard marine radar units are located on the bridge (see Figure 1). Wheelhouse construction is such that all bridge equipment is easily moveable so that the arrangement can be changed. Units can be added or deleted when it is desired to study the effect of a particular arrangement or unit on the performance of the bridge crew, or on the outcome of a particular situation. Bow and stern thrusters and twin screw controls are available.

Figure 1. Interior of wheelhouse showing bridge equipment

The wheelhouse is located at the center of a 60-foot diameter circular theater. On the walls of the theater, covering a 240-degree field of view, is the scene which is observed through the wheelhouse windows at the actual position and heading of the "own ship." As the "own ship" moves in response to the commands of the bridge crew, the scene changes appropriately. As many as six other moving traffic ships of various types can appear simultaneously in the scene. Up to 40 traffic ships can appear simultaneously in the radar display, since the radar can scan a much greater area than can be seen visually. The bridge is equipped with intercom and sound-powered phones for simulated communication to the engine room and other parts of "own ship," a ship's whistle, and radio equipment for communication with other traffic ships and shore installations.

Figure 2 shows the arrangement of the wheelhouse and the other major elements of the simulator within the CAORF building. The building was designed and delivered as part of the CAORF system. It increases the effectiveness of the system by providing a benign physical environment, maritime decor to enhance the mood, and an efficient arrangement for operation and maintenance.

CENTRAL DATA PROCESSOR

A central computer simulates propulsion and steering dynamics and hydrodynamics. It then solves the equations of motion of "own ship" in order to update the "own ship's" position and heading. The computer also updates the positions and headings of the traffic ships in the experiment. These are under the command of the Experiment Controller who is located in the Control Station, separate from the bridge crew. The computer sends the updated positions and headings of all of the ships plus information on sunlight and weather,

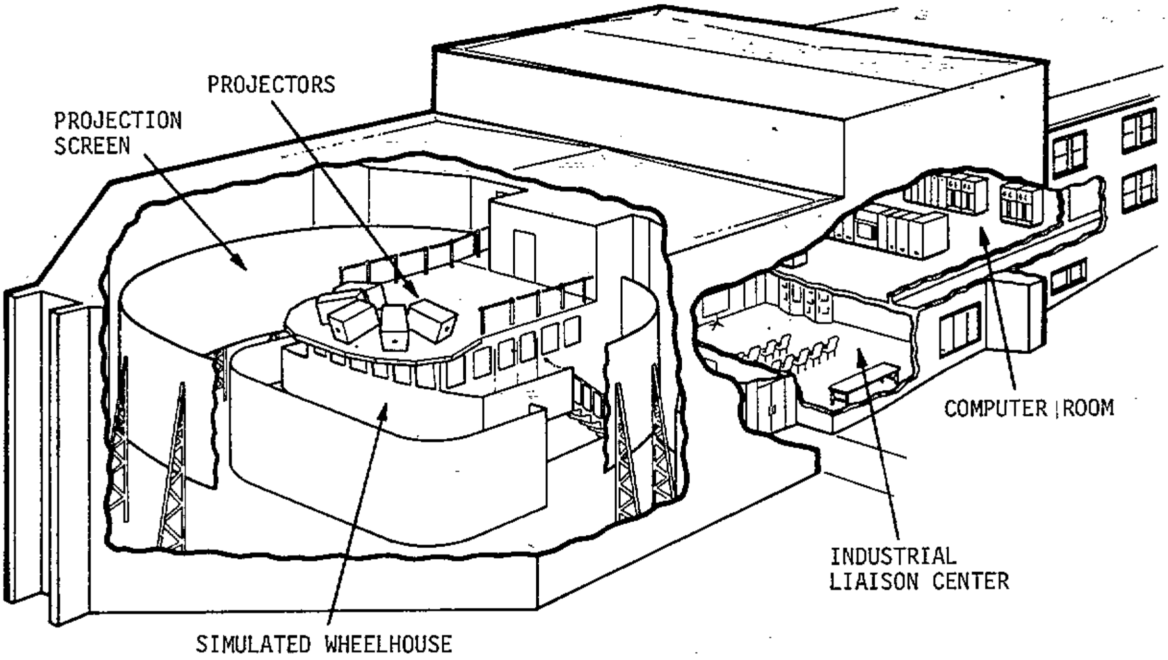

Figure 2. Cutaway view showing arrangement of elements of CAORF simulator in its building.

thirty times per second, to the appropriate bridge and control station instruments, three other dedicated computers which generate the visual scene, the radar displays on the bridge, and a map-like situation display in the Control Station. The central computer also coordinates all commands and data flow throughout the simulator. It records data for analysis and, if desired, playback of any desired portions of the experiment.

CONTROL STATION

The experiment is directed from the Control Station (see Figure 3) where the Experiment Controller and his assistants perform the following functions:

- Start and stop the experiment, change operating modes (e.g., "freeze" or "playback")
- Monitor experiment status and issue commands to the bridge crew as appropriate
- Control the insertion, motion, and the deletion of traffic ships in the visual scene and in the radar presentation
- Perform the functions of the engine room of the "own ship," providing communications, and changing propulsion or steering upon request from the bridge
- Provide voice and whistle communications as appropriate from other traffic ships, other parts of "own ship," and shore installations
- Control the weather, haze, fog, etc.
- Insert simulated failures of "own ship's" propulsion, steering, or electric power.

The Control Station is equipped with an equivalent set of bridge instruments and controls. Instead of a duplicate radar presentation, however, there is a situation display of equivalent size which presents a continually updated map of the experiment gaming area. The map shows shorelines, channels and buoys, and all traffic ships participating in the experiment, with symbolic indications of types, and vectors indicating heading and speed. The Experiment Controller has a choice of several scales and modes of presentation.

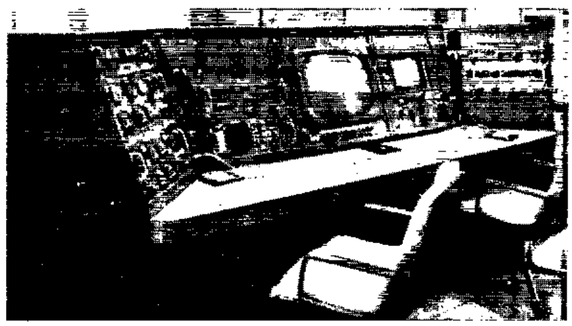

Figure 3. Control Station

The Control Station also includes appropriate "own ship's" intercom and sound-powered phones, and simulated radio channels for communications from other traffic ships and the shore. There is also an interactive CRT terminal and keyboard for communicating with the central computer and other controls as necessary for starting and terminating the experiment, changing operating modes, controlling visibility, inserting simulated equipment failures, and performing other functions.

SIGNAL PROCESSING PHILOSOPHY

Digital signal transmission and processing is used throughout the simulator in order to meet the basic system requirements more efficiently. For example, the signals to and from the bridge instruments and controls are converted to digital form adjacent to the bridge. All signals and commands, except voice communications, are routed through the central computer. In addition to simulating such functions as ship responses, the computer is able to coordinate and synchronize related events, thus giving a smooth and realistic overall simulation. Changes in many types of parameters, such as changes in ship's characteristics, insertion and deletion of traffic ships, and changes in types of ships, are facilitated by the use of digital data. This computer-centered configuration also facilitates the storage of information from the experiment for analysis.

As many as several hundred quantities can be recorded, if desired; the rate of recording can be selected by the Experiment Controller and varied during an experiment. There is also a playback mode where the experiment can be frozen at any time, and any previous portion can be repeated for instance, all simulated motion of "own ship" and traffic ships, visual and instrument displays, and changes in propulsion and steering commands are repeated in real-time for observation and analysis. Playback can be exercised during an experiment or at a later date. Figure 4 is a CAORF system functional flow diagram.

In an extension of this system philosophy, computer generated imagery (CGI) is used to create the three visual displays; the maritime scene in the theater viewed through the wheelhouse windows, the radar displays on the bridge, and the situation display in the control station. Each of these displays is generated by a separate, dedicated computer which is under the control of the central data processor. The use of separate data bases for the three displays was found to be more efficient. The visual scene is the most extensive of the three; its operation will be discussed next.

IMAGE GENERATOR AND DISPLAY

The data base for the visual scene is stored in the dedicated computer. When the position and heading of the "own ship" is received from the central data processor, the dedicated computer selects those elements of the data base which would be seen from the bridge of "own ship" at that position and heading. The selected scene elements are processed to show the proper range and aspect, and to eliminate elements hidden by closer elements. The scene is then converted to TV raster format for transmission to the display projectors. These operate on the Eidophor principle, similar to those used for closed-circuit TV presentations in large auditoriums. Figure 5 shows a typical computer generated visual scene in CAORF.

The use of CGI greatly enhances CAORF's capability to simulate and change several factors which have an important affect on crew performance. It greatly facilitates the inclusion of moving traffic ships in the scene. It permits total unrestricted movement and perspective change of the scene in response to motions of the simulated "own ships." Also, the eye position may be arbitrarily located in both height, fore, and aft directions. Thus, large or small "own ships," with bridges mounted either forward or aft, may be simulated. The bow of "own ship" can appear on the screen if appropriate; its appearance is that of the selected type of "own ship." To date, two oil tankers and one LNG tanker have been encoded for display. Others can be readily added as the need occurs.

The ambient illumination in the scene is continuously variable from day to night. In daytime scenes, the sun's position is suggested by highlights and shading on buildings, terrain, and other picture elements. In twilight and night scenes, the lights located on ships and on shore are controllable by groups. Each light is represented in its correct color, location, flashing pattern, and visibility range. Lights having a directional characteristic or color changes are so represented.

The area used, in the visual scene, for a single continuous exercise is normally 50 by 100 miles (the radar gaming area is appropriately larger to allow for the greater range of the radar on a ship which is located near the edge of the visual gaming area). If desired, the experiment may shift after a short interruption to a continuous gaming area of equal size. The gaming area represented in the present data base covers the approaches to New York through the narrows and through the Kill Van Kull to Port Newark. When more areas are encoded, exchanging one magnetic disk in the image generator computer will change the visual scene to represent a totally different area.

Within the limits of computer capacity, the scene encoded into the data base can show bridges, piers, buoys, buildings, terrain features, cranes, and other fixed objects of importance to mariners navigating in the harbor. Nautical charts, topographic maps, photographs, and other sources are used to assure the accuracy of presentation as well as the priority of feature selection in terms of importance to the mariner. Provision is made

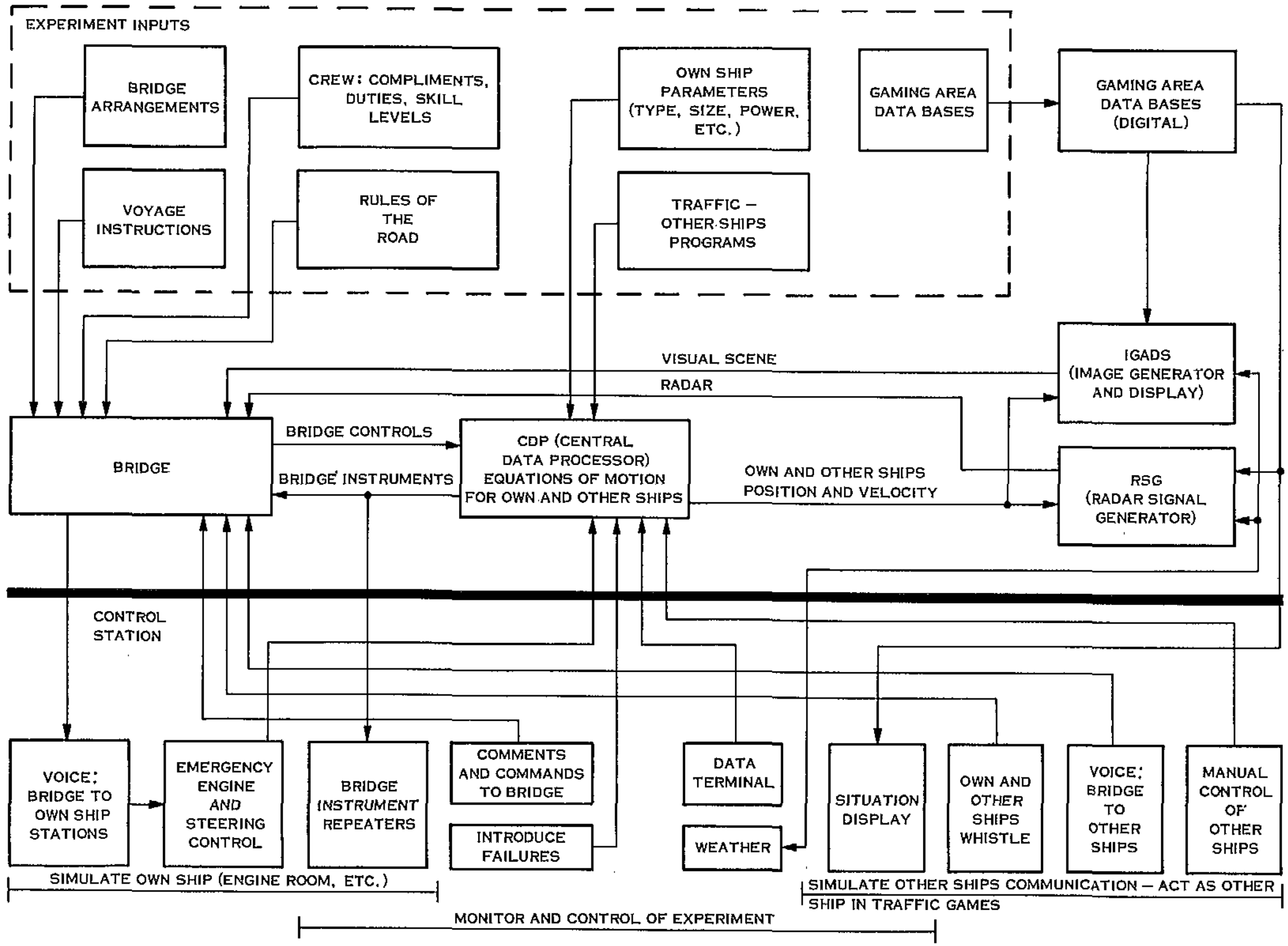

Figure 4. CAORF Functional Flow Diagram

Figure 5. Computer Generated Maritime Scene viewed through wheelhouse windows

to add or remove aids to navigation, or make other changes as warranted by Notices to Mariners.

One of the most dramatic features of the visual system is the presentation of fog. The image generator computer "knows" the distance from the viewer to each object in the scene. In response to a control setting, the scene is modified by contrast reduction with range to give a realistic impression of fog. Provision has also been made to show fog banks in a realistic manner so that lights or objects are partially or totally obscured as appropriate. The fog bank may move or ships may move through it.

CONCLUSION

This paper has covered some of the sys- tem aspects of the CAORF ship's bridge simulator. CAORF is designed for research into shiphandling problems, particularly the causes of collisions and groundings, and the performance of the bridge crew in stressful situations. These research problems are a fruitful application which can realize several of the unique advantages of simulation over investigations using real world equipment. The research simulator has the capability to simulate critical operational factors, which affect the outcome of the experiments, with sufficient realism to obtain valid crew performance, with the facility to vary each of the factors. CAORF consists of a full-scale ship's bridge, fully equipped with contemporary hardware, with digital handling of essentially all information and commands, and computer generated imagery to create maritime scenes. The scenes include sufficient numbers of moving traffic ships, weather effects, and harbour waterway configuration to simulate realistic problem situations. The cost of simulating marine operational problems in this way is considerably less than it could be in the actual vessel. Further, the simulation can include complex and hazardous conditions which are out of the question for operating vessels. The experiments can be conducted with the advantages of laboratory tests; properly skilled technicians recording results on scenarios undisturbed by unplanned intrusions, and undeflected by the crisis which may result from such intrusions. Simulation can provide experiments for entry into channels not yet dredged, and docks not yet built for ships not yet designed. This can yield data to improve maritime systems and operations.

ABOUT THE AUTHORS

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