Maritime Research at the Computer-Aided Operations Research Facility

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A description of the Computer-Aided Operations Research Facility (CAORF) ship-maneuvering simulator and an overall view of the experimental investigations performed in the three years of facility operation are presented. During this period, CAORF has been engaged in a wide variety of research programs directed toward application to commercial shipping. Among the investigations discussed are (a) a series of simulator experiments that deal with the effect of computer-based collision-avoidance systems on the performance of bridge watch officers in potential collision situations in the open sea and in restricted waters; (b) an evaluation of a marine radar interrogator-transponder system as an aid in collision avoidance and as a navigation aid to the bridge watch officer; (c) an assessment of the effects of wind speed on the safe docking of carriers of liquefied natural gas; (d) the use of off-line computer simulation to examine conditions for safe passage of large oil tankers [36 000 to 360 000 deadweight Mg (40 000 to 400 000 deadweight tons)] through selected straits in the Puget Sound area; and (e) the use of the simulator to analyze operational procedures in approaching and leaving new ports such as the port of Valdez, Alaska, and a new terminal for liquefied natural gas at Port Arun in Sumatra.

The U.S. Maritime Administration has established a research program that has three main objectives:

1. To reduce the number of ship accidents,
2. To develop operational criteria and standards to predict performance under expected future conditions, and
3. To improve the efficiency and productivity of ships and ports through improved concepts of design, manning, and operation.

As a major element in the plan to meet these objectives, the Maritime Administration in 1975 authorized the National Maritime Research Center (NMRC) to construct the Computer-Aided Operations Research Facility (CAORF) at Kings Point, New York, on the grounds of the U.S. Merchant Marine Academy.

DESCRIPTION OF CAORF SIMULATOR

CAORF is the most sophisticated and versatile ship-maneuvering simulator in the world. It provides a realistic shipboard environment by means of a full-scale wheelhouse and a complement of bridge hardware that can be found on most modern merchant ships. Included are relative-motion and true-motion radar capable of displaying up to 40 moving target ships, gyro pilot steering, engine order telegraph and throttle control, bow and stern thrusters, speed log, and complete communications equipment.

One of the extraordinary features of the simulator is a computer-generated visual image of the outside world as seen through the wheelhouse windows. The image is projected as a television picture on an 18-m (60-ft) diameter cylindrical screen around the bridge and covers a field of view 240° in relative bearing and 24° in elevation. Detailed, full-color presentations are provided of coastlines, bridges, buildings, piers, other significant elements of the visual environment, and as many as six moving ships. The scene includes the forebody of the "ownship", which is superimposed on the centerline of the screen. The visual scene changes in real time in accurate response to the maneuvering motions of ownship and other ship. Figure 1 shows a typical visual scene as viewed from the CAORF wheelhouse.

Other unique characteristics of CAORF include the ability to (a) simulate fog or haze, (b) control the illumination level so that either day or night scenes can be simulated, (c) vary the generated scene in proportion to the watchkeeper's height of eye above the waterline for the particular ownship being simulated, and (d) change the data base to simulate any port in the world.

Inventory of Ships and Ports

Today there are seven tankers in the CAORF ownship data base [ranging in size from 27 000 to 360 000 Mg (30 000 to 400 000 tons)] as well as two liquefied natural gas (LNG) ships, a containership, and a modern cargo ship. As with all CAORF simulations, the data representative of a particular ship are entered in the computer from hydrodynamic, propulsion, and other coefficients calculated or measured from data provided by the owner or operator. These data are obtained from design and construction plans and actual sea trials. Experienced masters or pilots who have handled that ship then review its maneuvering performance at CAORF and advise on any adjustments that would provide a fully realistic simulation.

The visual scene at CAORF is constructed in the same careful manner. All navigational cues and characteristics of the particular harbor are entered in sufficient detail to permit a realistic simulation of the area under study. In the New York Harbor simulation, for example, as ownship passes beneath the Verrazano Bridge, the Statue of Liberty and the World Trade Center towers are seen in the upper bay. The "gaming areas" currently available at CAORF now total almost 20.

Unobtrusive Monitoring

Two other CAORF features of particular interest are the human factors monitoring station and the control station. Through closed-circuit television and microphones on the bridge, the monitoring station permits an observer to follow unobtrusively everything that is happening in the wheelhouse and to see the same visual display the navigator on the bridge sees. The control station is the central location from which every simulator experiment is controlled and monitored. Researchers at the control station can initiate an experiment anywhere within the visual gaming area. They can simulate malfunctions, control the operating mode of ownship, direct traffic ships and tugs in the gaming area, and simulate telephone, intercom, radio, and whistle contact with the CAORF bridge crew.

Figure 1. Typical simulated visual scene at CAORF.

EXPERIMENTS IN COLLISION AVOIDANCE

Open-Sea Study

The first in a series of experiments in collision avoidance at CAORF involved an open-sea study in which the effectiveness of three navigation modes was compared. The modes tested were visual, radar, and a collision-avoidance system (CAS). The CAS used in the experiment superimposes computer-generated anticollision data on a conventional radar screen. For each traffic ship the navigator chooses to acquire, a predicted area of danger (PAD) appears on the screen (see Figure 2). The PAD is an elliptical symbol that covers an area that ownship must avoid if it is to maintain a given distance from a traffic ship.

The object of the experiment was to compare the collision-avoidance performance of a ship as it navigates through the same situations in each of the three navigational modes. The six test subjects, each of whom held a master's license, commanded a 73 000-deadweight-Mg (80 000-deadweight-ton) tanker making 7.7 m/s (15 knots) in clear visibility through 10 situations that ranged in complexity from one-ship to five-ship situations. In brief summary, the test subjects who used the CAS had a mean "miss distance" from traffic ships one-third greater than that obtained by test subjects who used only visual methods and those who used radar plus visual methods.

Study of Restricted Waterways

As valuable as anticollision research is for open-sea situations, about 80 percent of marine accidents occur in restricted waters, where maneuvering is limited by a channel edge, nearby shoals, or land masses. This led to a CAORF experiment to determine the anticollision effectiveness in a congested harbor approach area of radar, the PAD-type CAS, and a PAD-type CAS that has a "navigation option". Disorientation is often a factor in accidents in restricted waterways, and the navigation option reduces this by superimposing a basic chart of the navigational area on the CAS display. The results of this experiment are still being analyzed, but the data for collisions, groundings, and near misses indicate a clear advantage for the PAD-type CAS with the navigation option.

RESEARCH IN ADVANCED BRIDGE SYSTEMS

Marine Radar Interrogator-Transponder System

Considerable experimental work at CAORF has been done on new and advanced bridge navigation systems. One of these experiments studied a marine radar interrogator-transponder (MRIT) system as a navigation aid. Navigators were asked to conn the ship along a four-legged channel 909 m (3000 ft) wide and to adhere as closely as possible to the centerline of the channel. Test subjects did this visually by using radar, racons, and MRIT digital and analog displays. The two types of MRIT displays are shown in Figure 3 (U.S. customary units are used in the digital display shown in Figure 3a). Test subjects consistently adhered to the center of the channel most closely when they used the MRIT system.

Docking Aid

A CAORF experiment to evaluate a docking aid was carried out at the site of a projected LNG terminal at Point Conception, California. It is known that opera-

Figure 2. Two types of PAD-type CAS display: (a) without navigation option and (b) with navigation option.

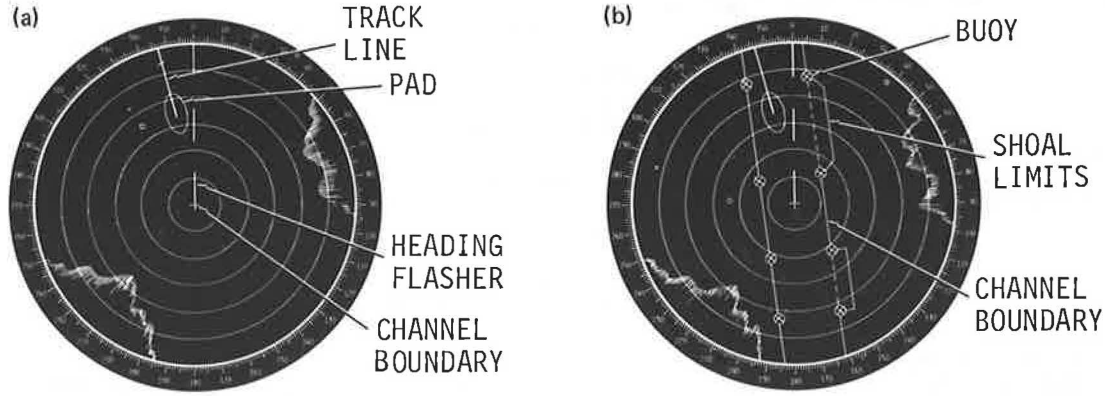
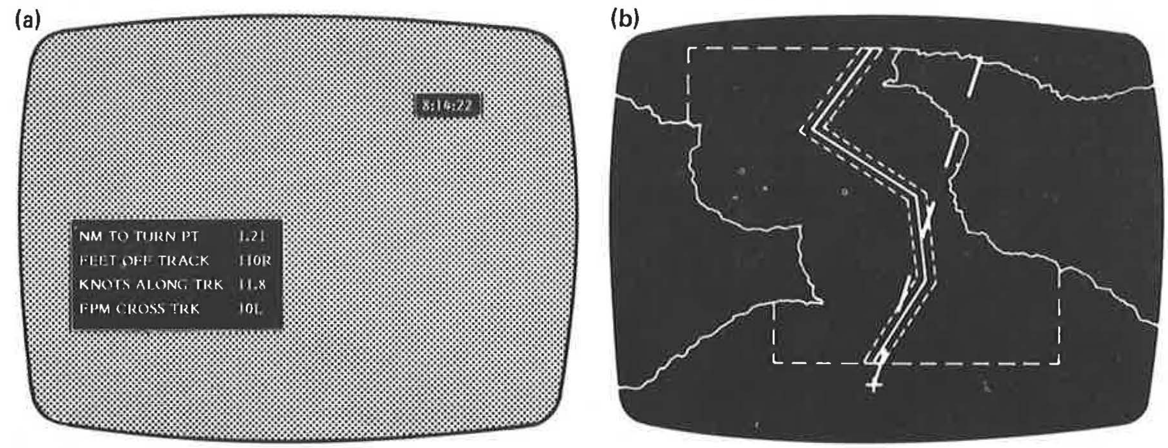


Figure 3. Two types of MRIT display: (a) digital and (b) analog.



tionally significant docking speeds often lie below the threshold of human motion perception. In the California experiment, the pilot on the bridge had access to digital information on ownship's true motion relative to the dock. A video monitor provided him with a visual presentation of the navigational scene and included a crosshair that marked ownship's center of gravity, a vector to indicate speed and direction of movement, and a simplified plan view of a trestle pier.

The results indicate that, by using the true motion vector display, docking pilots are able to dock an LNG carrier safely under a variety of low to moderate wind conditions. But the experiment raises concern about the safety of docking under high wind conditions [greater than 13 m/s (25 knots)], particularly when there is an offshore wind.

Precise Navigator

Another advanced bridge system investigated at CAORF is the precise navigator, a system in which an electronic aid provides the pilot with graphic and digital information on a video screen. Ownship's position relative to the channel center and ownship's true motion vector are displayed symbolically. Ownship's cross track position left or right of the center of the channel is shown digitally in the lower left corner of the video display.

NAVIGATION IN RESTRICTED WATERS

Buoy Placement

CAORF has conducted a series of basic experiments to determine the effectiveness of various buoy configurations—i.e., the optimum placement of aids to navigation in conditions that range from wide, placid channels where no other ships are present to heavily trafficked, narrow channels that have significant currents. Among the findings were the following:

1. Track keeping was generally better with a staggered buoy system than with a parallel system, and mariners had more difficulty in maintaining track when wind and current were weak than when these elements were strong.
2. The burden placed on the watch officer when the ship is navigating in fog and other ships are present was shown by a number of collisions with buoys and instances of ownship crossing out of the channel limits.

Relative Effectiveness of Navigational Aids

A series of restricted-waterways experiments at CAORF examined the effectiveness of various navigational aids in straight and dog-leg channels under various traffic, wind, current, and visibility conditions. The experiments, the complete results of which are still being analyzed, compared turning-point buoys with corner buoys, visual navigation with radar, and the effectiveness of a precise navigator in maintaining track in wide and narrow channels.

RESEARCH IN SPECIFIC WATERWAYS

A number of port and harbor simulations have been entered in the CAORF data bases for use in various experiments. Those described below can be considered typical.

Valdez, Alaska

In the spring of 1977, a CAORF study was made for the U.S. Maritime Administration to determine conditions needed for safe passage of very large crude carriers (VLCCs) in and out of the port of Valdez, Alaska. The Valdez experiment examined the effects of power and steering failures at different speeds under various conditions of wind and current. Comparisons were made between high visibility and fog and between various navigational aids, including radar and the experimental precise navigation system. The experiment was successful in determining safe operating limits for the Valdez trade.

Puget Sound

CAORF undertook a combination off-line and simulator study for the U.S. Coast Guard to help in determining whether tankers that range in deadweight from 36 000 to 360 000 Mg (40 000 to 400 000 tons) could be navigated safely through certain straits in Puget Sound. The CAORF work defined maximum and minimum speeds required for various winds and currents, the need for tugs, critical navigational areas in the sound, and emergency procedures to be used in the event of equipment failure.

Port Arun, Sumatra

The unique qualities of the CAORF simulator led to another operational exercise in the summer of 1978. A U.S. flagship operator was preparing to take delivery of LNG carriers under construction for service to a new port being built in Sumatra. Operational experience in entering the port and docking the ships under various combinations of wind, current, and visibility would have obvious value for the company's masters and mates and would also provide CAORF with basic data on one of the most critical aspects of modern ocean shipping.

Agreement was reached to conduct the exercise, and a detailed representation of Port Arun, Sumatra, was created from plans and photographs furnished by the operator. Three weeks elasped between receipt of the plans and completion of the simulation.

The operational exercise consisted of 5 d of extensive simulator runs and detailed briefings and debriefings during which the masters and mates experienced both familiarization runs and a number of maneuvering exercises selected by the owners from a list prepared by CAORF. A series of emergency and failure runs were also made. The Port Arun runs were approaches to the harbor and docking and undocking simulations with various winds and currents and with and without tugs.

The Port Arun exercise demonstrated a cooperative interaction between government and industry to benefit both an individual operator and, through enhanced CAORF data bases on ship operation and port design, the U.S. maritime industry in general.

Galveston, Texas

A study now being made for the port of Galveston, Texas, typifies the CAORF potential for helping to determine safe and economical methods of ship operation. Deep-draft VLCCs used to import crude oil ordinarily must be lightered offshore by smaller tankers—a costly and time-consuming process. In the Galveston plan, tankers that range in deadweight from 227 000 to 263 000 Mg (250 000 to 290 000 tons) would be lightered offshore but only to drafts of 15 m (50 ft). The big ships would then navigate a narrow channel [17 to 17.5 m (56 to 58 ft)] to pipeline terminals 32 km (20 miles) inland. The questions that CAORF will answer include

1. What is the effect on ship control as the forebody of a tanker more than 303 m (1000 ft) long passes out of a current and enters a narrow, protected channel at slow speed?
2. What is a safe channel speed under the expected wind, current, and visibility conditions?
3. What critical channel areas (e.g., turning points) require special precautions?
4. How many tugs will be needed, what power should they be, and how should they be deployed?
5. What procedures will be required in case of equipment failure?

HUMAN FACTORS STUDIES

CAORF research extends beyond the hardware and harbor evaluations that are the focal point of most experimental work at the facility. Measures are being developed at CAORF to define the limit of the mariner's decision-making capability in various situations, to measure human performance with various bridge systems, and to identify situations in which the operator may require additional aids. Experimental methodologies are being developed to evaluate the effectiveness of ship simulator training and the optimal format and hardware for such training. A variety of CAORF experiments measure the mental and bodily reactions of test subjects—e.g., the psychophysiological significance of task-induced and environmental stress associated with some navigational situations. Behavior exhibited in collision avoidance and similar situations at CAORF is noted for comparison with established data to reveal risk-taking tendencies among masters or mates in command of ownship.

THE FUTURE

CAORF is still being upgraded and will continue to be for several years. When the simulator became operational, it was known that additions and modifications would be needed and would have to be incorporated as time and budget permitted.

An early change was the addition of a second computer that provides some spare capacity to expand the system and also permits off-line research while the simulator is being used for experiments. Among the 1977 additions to CAORF were the capability of simulating wind, current, and tug forces. In 1978, effects of shallow water, new bridge displays, a second conning station, an improved communications system, and ship passing effects were all added. This year the system is to be expanded to include bank effects, more realistic tug simulations, and variable winds and currents.

Over the long term, the collision analysis experiments at CAORF will study all phases of equipment and procedures in an attempt to provide the industry with a firm basis for selecting navigational hardware and determining training requirements. Until now, ship controllability and maneuvering margins have been based on experience, intuition, and rules of thumb. CAORF plans to develop indexes of controllability for safely navigating ships in confined areas. The ultimate goal is to model human performance with sufficient accuracy to predict how a ship design will perform in a specific waterway for a range of pilot and helmsman capability.

CAORF studies of bridge design will focus on layouts of equipment, the nature and amount of information to be presented, types of displays and controls, and the relations of such equipment to the functions of the watch.

The long-range aim in analysis of harbors and restricted waterways is to produce design information for port and harbor designers and data on which safe and productive procedures for waterway operations can be based. All aspects of the effects of local environment on ships' pilots will be considered, from manmade navigation aids to how pilots use the cues available in land features.

A primary objective of training and licensing research is to determine how simulators can and should be used in training watch officers. The plan is to suggest what level of simulators will suffice for any area of training in which costs and benefits can be justified and to contribute to the specification of such simulators.

Publication of this paper sponsored by Committee on Simulation and Measurement of Driving.

Locomotive Engineer Training: State of the Art

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A training program developed by the Santa Fe Railway to train individuals for the position of locomotive engineer on today's railroads is described. The program uses the traditional method of the fireman-engineer relationship in conjunction with classroom instruction and locomotive and train simulation. Its ultimate objective is to produce people who have the best possible qualifications to operate locomotives and handle trains safely and efficiently. The Santa Fe Railway feels that standardization of instruction is the key to reaching this goal and that centralized training and the use of simulation have proved to be the best way to achieve standardization.

The history of railroading in North America has been exciting, romantic, violent, pioneering, and important. Over the past 100 years, railroads have criss-crossed the country, opened it to civilization, and served it at war and in peace.

Even 100 years ago, the railroads were a growing dynamic force, always looking for new and better ways to do things. They searched for and came up with efficient new designs in rolling stock and developed highly flexible piggy-back loading, powerful new locomotives, and coal train service to meet modern demands. Throughout this period, however, the training of those responsible for operating the locomotive fleet on the railroads of North America has remained essentially the same.

Traditionally, a fireman-engineer relationship was the basis for engineer training. The system grew out of need, and the relationship and the system seemed logical because no one had developed a better way to train locomotive engineers. Firemen rode with the engineer, performing various duties under the engineer's direction for a four-year incremental period, observing, assisting, occasionally participating, hopefully retaining what they could, and being periodically tested under actual operational conditions. Finally, at the end of the period, firemen were given a final examination that, if passed successfully, qualified them as locomotive engineers.

The problem with this method of training was that the training was only as good as the supervising engineer. Because each engineer taught the job as he understood it, many trainees unknowingly picked up bad habits. This four-year program of learning by osmosis remained virtually unchanged until the present decade.

In the late 1960s, railroads were faced with a predicament. With an ever-increasing influx of business and a growing retirement rate among locomotive engineers, they found themselves facing the problem of getting enough qualified people to operate locomotives in order to move millions of tons of freight to its destination. As a result, various types of training programs were instituted. Each railroad had its own version. Some stayed with the traditional fireman-engineer method whereas others used the same method but added classroom instruction. A few used both methods and incorporated the use of locomotive and train simulation.

In 1968, the Santa Fe Railway initiated the purchase of a locomotive and train simulator from the Link Division of the Singer Company. Sophisticated training and simulation equipment was, by now, an accepted way of life in aviation. But what about the job of a locomotive engineer? Was it possible to teach people the basics of operating a modern locomotive with a long string of loaded cars behind them? Was it possible to train them without making frequent expensive trial runs? The management of the Santa Fe Railway answered yes to these questions at that time, and the answer remains the same today.

The Santa Fe Railway took possession of the locomotive simulator from Link in 1969. A locomotive engineer training program was formulated, and in 1970 the first formal training class was held for the purpose of promotion to locomotive engineer. This paper provides a basic description of the training program as it is today on the Santa Fe Railway.