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Safety of Bridges and Offshore Structures - the Role of Ship Simulation

Sécurité des ponts et des constructions offshore - rôle de la simulation navale

Sicherheit bei Brücken und Offshore-Bauten - die Bedeutung der Schiffsimulation

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SUMMARY

Bridge safety is not solely structural safety. There is an inherent variability in the operation of ships. This variability precludes absolute assurance that a bridge or other structure will not be damaged by a ship if such damage is physically possible. Some of the variability is inherent in human performance; other parts of it relate to environmental conditions and the availability and adequacy of information. In any event, it is only the human beings directing ship movements who can preclude out-of-tolerance variance. For this reason, all efforts at ship operational safety, including those of bridge and structural engineers, should be oriented to the point of view of the human pilot or master who will direct the ship. Simulation and simulators can help in that process.

RÉSUMÉ

La sécurité des ponts n'est pas seulement une question de sécurité structurelle. Le mouvement des navires représente un risque inévitable. Ce risque exclue la garantie absolue qu'un pont ou autre structure ne sera pas endommagé par un navire si un tel dommage est physiquement possible. Une partie de ce risque est due au facteur humain, d'autres parties sont causées par l'environnement et par les sources d'information. En tous cas, seuls les êtres humains qui dirigent les mouvements du navire peuvent exclure un risque intolérable. Dans ce but, tous les efforts y compris ceux des ingénieurs de ponts et de structures, pour tendre à la sécurité des mouvements de navire, doivent être orientés vers le point de vue du pilote humain ou le capitaine du navire. La simulation peut contribuer à cet effort.

ZUSAMMENFASSUNG

Brückensicherheit ist nicht nur eine Frage der Sicherheit des Bauwerks. Der Schifffahrt wohnt eine ständige Veränderlichkeit inne. Dieses Risiko bildet keine absolute Gewähr dafür aus, dass eine Brücke oder ein anderes Bauwerk von einem Schiff nicht beschädigt wird, wenn eine solche Beschädigung physisch möglich ist. Ein Teil des Risikos ist auf menschliche Faktoren zurückzuführen, andere Teile rühren von umweltmässigen Faktoren sowie von der informationsquellen her. Unter allen Umständen sind nur die Leute, die Schiffe steuern, instande, ein nicht annehmbares Risiko auszuschliessen. Alle Bestrebungen zur Erhöhung der Schifffahrtsicherheit einschliesslich der der Brückenbauingenieure, müssen deshalb auf die Ansicht des menschlichen Pilots oder des Schiffführers, der das Schiff steuern wird, ausgerichtet werden. Simulation kann bei diesem Prozess behilflich sein.

1. INTRODUCTION

Throughout the world, there are hundreds of thousands of bridges to carry rail, highway, or foot traffic over navigable waterways. In many cases, the bridges seem to be armored massive bastions compared to the frail shells of craft which glide beneath them. One would not expect a straying gondola to damage the Bridge of Sighs in Venice.

Increasingly, however, ships tend themselves to be ponderous behemoths of masses and momentums against which virtually no bridge can stand. If we assume that these huge ships will continue to "attack" bridges, adding sufficient armored mass to the bridge structure itself seems an impossible defense. It would be better to provide a neutral "buffer zone". This means restricting bridge supports and low spans to locations where the surrounding waters are so shallow that any stray ship of sufficient mass to damage the bridge would be summarily halted hard aground before it could reach the structure.

In cases where this is infeasible, it is necessary for bridges to negotiate with ships. Bridges could defend themselves better by provoking ships less. Especially provocative is the practice of locating bridges near sharp bends in the navigation channels. Placing two or more bridges close to each other, with narrow openings, with openings misaligned relative to patterns of current flow, and requiring a lift span rather than providing for a high fixed span are all somewhat provocative. To combine several of these provocations in a single location is to invite "attack".

Bridges may also invite a "jostling" by haughtily ignoring ships rather than speaking politely to them. It is "courteous" for a bridge to "speak" using day markers and lights or radar reflectors to mark the channel location.

Bridges can strengthen their diplomatic status further by allying themselves with allies of the ship, especially channels/basins of adequate width and depth and good aids to navigation. If a ship gets out of control upstream due in part to overly confined waters and poor information, both the ship and bridge may be helpless as the natural flows bring them together.

Even the most courteous and diplomatic bridge cannot effectively limit the degree of variability in the passage of ships beneath it. Only the human beings controlling the ships can do that. It may well be that the best way for us to avoid bruising steel and concrete realities is through creative and imaginative use of structured unrealities.

2. SHIP ACCIDENTS WITH BRIDGES

2.1 Some Specific Accidents With Bridges

2.1.1 AFRICAN NEPTUNE - Sidney Lanier Bridge[1]

Shortly after leaving the State Docks in Brunswick, Georgia, on the evening of 7 November 1972, the AFRICAN NEPTUNE struck the Sidney Lanier Bridge 350 feet south of the channel centerline. Three sections of the bridge and ten vehicles fell into the river, killing ten persons and injuring eleven. The bridge was closed for about six months. Repair costs were approximately US$1.3 million. The National Transportation Safety Board determined that the probable cause was (1) the failure of the third mate to apply the correct rudder in response to two helm orders; (2) the failure of the third mate, master and pilot to discover the first error and (3) their delay in detecting and correcting the second error.[1]

2.1.2 MARINE FLORIDIAN - Benjamin Harrison Memorial Bridge

On 24 February 1977, the SS MARINE FLORIDIAN experienced a steering system failure about 500 meters from the Benjamin Harrison highway bridge. The resulting collision collapsed the northern tower span. On 6 March 1977, the span, including the northern main tower of the bridge collapsed onto the vessel and into the river. Total damage to the bridge and the vessel was estimated to be US$8.5 million. The National Transportation Safety Board determined that the probable cause was inadequate maintenance and inspection of a manual transfer switch in the electrical circuit, which opened by gravity and interrupted power to the steering motor. Contributing causes were the operation of the vessel at a speed higher than necessary for a safe passage, failure of the steering alarm to function, and not having any person on watch in the steering engineroom, which precluded prompt activation of the alternate steering engine.[2]

2.1.3 Motor Vessel STUD - Southern Pacific Railroad Bridge over the Atchafalaya River near Berwick Bay, Louisiana.

On 1 April 1978, a four-barge tow with the Motor Vessel STUD collided with the eastern fixed span of the Berwick Bay railroad bridge and knocked the span from its supporting piers into the river. Damage to the STUD, a push towboat, was estimated at US$4,000. Bridge damage was US$1.4 million, including the cost of replacing the bridge span and rerouting rail traffic for eight days. The National Transportation Safety Board determined that the probable cause of the accident was the failure of the master to align his tow properly. Contributing factors were inadequate criteria for commencing high water limitations in the Berwick Bay Vessel Traffic Service area, inadequate horsepower of the STUD relative to the length of its tow and the maneuvering conditions, and the master's lack of timely information concerning the river stage and velocity.[3]

2.1.4 SUMMIT VENTURE - Sunshine Skyway Bridge, Tampa Bay, Florida

On 9 May 1980, the SUMMIT VENTURE struck and destroyed a support pier of the Sunshine Skyway Bridge over Tampa Bay, Florida. About 395 meters of bridge deck and superstructure fell into the bay from a height of about 46 meters. Thirty-five people died as several vehicles plunged into the bay. Repair costs were estimated at about US$30 million for the bridge and US$1 million for the SUMMIT VENTURE. The National Transportation Safety Board determined that the probable causes of this accident were a line of intense thunderstorms which overtook the vessel as it approached the bridge and the pilot's failure to abandon the transit despite losing his visual and radar references for the channel and bridge in the heavy rain. Contributing to the loss of life was the lack of a structural pier protection system which could have absorbed some of the impact force or redirected the vessel. Also contributing to the loss of life was the lack of a motorist warning system.[4]

2.2 Generic Causes of Bridge Collisions

2.2.1 Bridge Collision Studies

In the mid-1970's, a study was conducted of bridge collsions in the United States.[5] The larger number of these accidents involve push towboats and barges on our river and inland waterway system. Generally, these vessels make more bridge passages per day of operation than do large ships. As a result, there are more reported bridge accidents involving these vessels from which to establish causal patterns. These patterns can be applied to situations involving larger ships by assessing the relevance of specific factors to particular vessels, bridges and local traffic.

The primary cause of towboat accidents with bridges is loss of control on the approach to the bridge. In seventy-three percent of the towboat cases studied, the loss of control was due to a current-induced rotation and delayed operator correction. The forces that cause rotation increase linearly as the angle of rotation increases. In many scenarios a critical angle of rotation can be reached where recovery is impossible. One of the reasons delaying operator correction is the difficulty of perceiving the onset of rotation, especially at night. Most current caused accidents occur at night and to loaded vessels, some of which seem to be underpowered. Most wind caused accidents occur in daylight, to vessels in ballast, and are due to unique conditions at specific bridges. The major ways to reduce these accidents are to improve the navigability of the bridge approaches, to improve the quality and timeliness of information to the vessel operator (see section 5.3.2), and to assure adequate power availability for loaded vessels. In the case of some ship passages, assisting tugboats may be necessary.

2.2.2 Human and Physical Factors in Vessel Accidents

Regarding the human factors involved, we conducted studies from 1976 through 1979 to identify shiphandling tasks and any deficiencies in task performance contributing to accidents.[6,7,8] Most vessel accidents occur to highly competent and experienced personnel who are in good physical and mental condition. There are, of course, exceptions where accidents are caused by personnel who are excessively fatigued, ill, incompetent or affected by drugs, alcohol, medication, or emotional stress. Similarly, the majority of vessels involved in the accidents experienced no failure of their control mechanisms, although steering and propulsion failures do cause a minority of the accidents. Only about twenty percent of these accidents are due to tangible equipment or operator failings.

The dominant characteristics of vessel collisions with bridges are geometric and environmental. Geometric factors are primarily the placement of bridges near bends in the navigation channel, the relative sizes of the vessels and the bridge spans, and the adequacy of line-of-sight information (visual and radar). Environmental factors of note are following currents, cross currents, current speed, cross winds, wind speed, and factors reducing visibility or radar performance. Operational factors include traffic or other obstacles near or in the bridge approach channel, reserve power available with or without tugs, and the timing of drawbridge operations.

We lack good data on the relative frequency of ship passages through drawbridges as contrasted with fixed span brdiges. Thus, the relative risks are not known. It was observed, however, that over half of harbor bridge rammings were at drawbridges. The involvement of a moving span does introduce added risk factors over fixed spans. Apart from possible problems of timing the bridge opening and possible failure of the bridge mechanism, there are serious risks of communication problems between bridge and vessel personnel.

2.2.3 Possibilities for Improving Bridge Navigability

Critical shiphandling requirements in general are summarized in Figure 1. from a variety of studies. These were selected in the process of identifying skills that might be usefully improved through ship simulator training. Many of these same factors, however, can also be addressed by local port authorities or by other authorities at their request. Examples are placement and design of rail or highway bridges (avoiding drawbridges and locations near river bends), improving aids to navigation to make them more useful and reliable, widening or deepening channels, and establishing special local rules or procedures regarding traffic, speed and use of tugboats.

		ORI [8,9]	TAEG [11]	NTSB [12]	SHIPPING COMPANY ANALYSIS [13]	T & L WORKING GROUP	DET NORSKE VERITAS [14]	MTRB [15]
	VESSEL TO VESSEL COMMS	●	◒	●	○	○	○	◒
	SHIPHANDLING					●	◒	
	– SAFE SPEED	◒		●				
	– MAINTAINING POSITION	●						
	– COMPENSATING FOR EXTERNAL FORCES		◒					
RESTRICTED WATERS NAVIGATION MANAGEMENT	PILOT/MASTER RELATIONSHIP	◒	◒	●	●	●		●
	BRIDGE PROCEDURES			●	●	○	◒	●
	– LATE DETECTION	●						
	– FAILURE TO MONITOR OTHER VESSEL	◒						
	– FAILURE TO ESTABLISH NAVIGATION POSITION	◒						
	– FAILURE TO TAKE ADEQUATE FIXES		◒					
	BRIDGE ORGANIZATION			◒	●			○
	– VESSEL MANNING						●	
	RULES-OF-THE-ROAD		○	●		●	◒	○
	EMERGENCY SHIPHANDLING					●		
	NAVIGATION				◒		◒	○
	– FAILURE TO ESTABLISH NAVIGATION POSITION	◒						
	– FAILURE TO TAKE ADEQUATE FIXES	◒						

● DENOTES HIGH CRITICALITY STRESSED

◒ DENOTES MEDIUM CRITICALITY NOTED

○ DENOTES IMPLIED CRITICALITY INTERPRETED

Figure 1. Summary of Critical Shiphandling Skills

The U. S. Coast Guard, among other functions, has a Bridge Administration Program "to ensure safe and reasonably unobstructive navigation through or under bridges spanning the navigable waters of the United States, while meeting the needs of other transportation modes and protecting the human environment."[9] This program includes bridge lighting for navigation, regulation of drawbridge operations, approval of new or replacement bridge locations and plans, and removal or alteration of existing bridges at public expense if it is determined that a bridge obstructs navigation in an unreasonable way as a result of changes in the needs of navigation.[10]

3. OFFSHORE STRUCTURE RISKS

3.1 TEXACO NORTH DAKOTA Collision with Artificial Island EI-361-A

3.1.1 Accident Report Summary

About 0430 on 21 August 1980 the TEXACO NORTH DAKOTA collided with a partially constructed artificial island for oil production. See Figure 2. The forward cargo tanks were ruptured resulting in a fire that destroyed the forward part of the cargo tank area and the midships house. The fire burned for several days before it was extinguished by a professional firefighting team. The salvaged vessel was later declared a constructive total loss. The damage to the artificial island was at least US$11 million and possibly more than US$12.6 million. The owner decided not to repair the structure. The National Transportation Safety Board determined that the probable cause of the accident was the failure of the system which provided information about the location of hazards to navigation do so in this case, the failure of the ship's master to acquaint himself with the latest marine information before navigating near offshore structures on the outer continental shelf. A contributing factor was the failure of the marine constuction company to maintain the aids to navigation on the offshore structure.[16]

3.1.2 Aids to Navigation

Navigation lights were installed on the partially constructed oil rig on 24 July 1980. The lights had not operated after Hurricane Allen passed through the area 8-11 August 1980. The platform builder requested an inspection and servicing of these lights on 13 August. On or after 22 August, the service contractor replied that the inpection had not been made due to the large numbers of service requests received.

3.1.3 Advisory Information

Information regarding the aids on the platform was published in a Local Notice to Mariners on 1 August 1980 but not in a Weekly Notice until 30 August. The vessel sailed on 4 August 1980, not having either notice. It was not clear whether local notices were ever used by the ship, although weekly notices were used regularly. From 8-22 August 1980, the U. S. Coast Guard Eighth District broadcast a generic warning about storm damage to warning lights on rigs. It was not clear to the safety board whether such broadcast warnings were recorded or heeded aboard the ship.

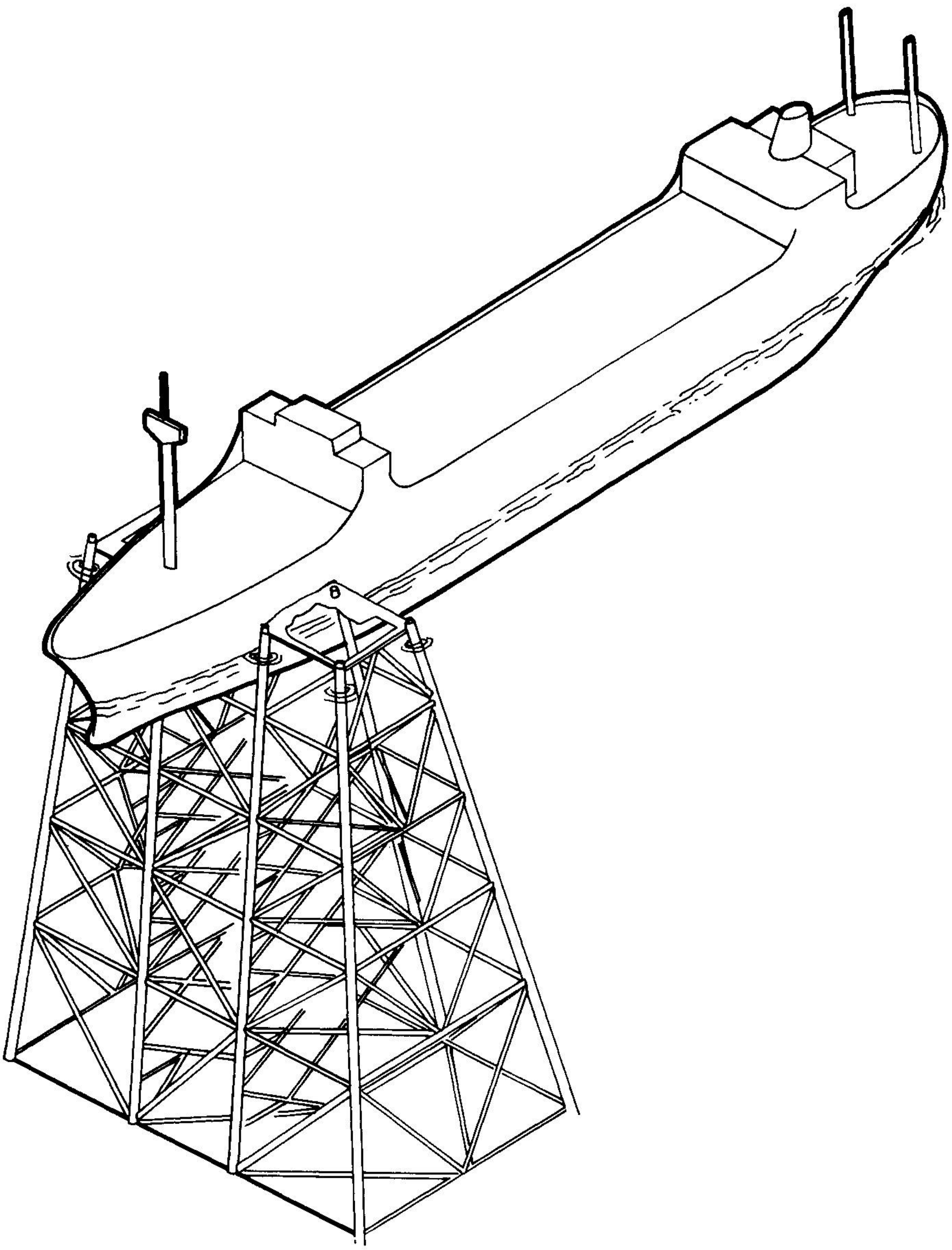

Figure 2.-Sketch showing TEXACO NORTH DAKOTA impaled on well jacket.

3.1.4 Waterway Information

To provide vessels with reasonably safe shipping lanes along the Gulf Coast, a system of Shipping Safety Fairways were established. The fairways are unmarked and are approximately two miles wide. Oil well or other fixed structures are not permitted within these fairways although several have been erected on the edges of fairways. Mariners are advised by the Coast Pilot to take advantage of the safe passageways made available by these fairways, but their use is not mandatory. Many vessels continue to use courses outside the fairways, opting to "run the rigs" based on their local knowledge. Testimony before the safety board revealed that the fairways are mostly used by foreign vessels.

3.1.5 Information Bearing on Rig Detectability

The ship lookout capability consisted of two radars and seamen's visual lookout. Of these, one radar was turned off. The operative radar had a three degree blind sector slightly left of due ahead. The watch officer was aware of the blind sector. Although it seems likely that the island was in the ship radar's blind sector just preceding the collision, it is also true that the tublular steel structure of the artificial island presents only one fourth the echo strength of a plane or a corner radar reflector. Visually, it was a clear, dark morning. The lookout was placed on the port bridge wing although he might have been stationed at the bow of the 172 meter ship. He warned the watch officer of the island too late to avoid the collision.

3.2 General Considerations in the Risk of Ship Collisions with Offshore Structures

3.2.1 Risk Analysis Approaches

The term risk analysis often refers to a probability distribution of adverse deviations from some safe or desired norm. In the case of ship operations, the safe norm is usually taken to be a nominal representative trackline. Models may then be postulated which assume an inverse relationship between the magnitude of track deviation and the probability of the deviation being that large. Alternatively, data on historical accidents are modeled in relation to data or projections regarding some "exposure" variable such as ship trips, volume of cargo carried, or simply time. Given estimates of risk, decision-makers are supposed to decide whether the risks are "acceptable." While such calculations have some intuitive appeal, inherent fallacies of such approaches led this author to present an argument against this whole risk assessment/acceptance approach at the 1982 Annual Meeting of the American Association for the Advancement of Science.[17] A written version, entitled "The Technological Risk Acceptance Myth," is in preparation. For the matter at hand, the following considerations are sufficient:

-There is seldom a single representative trackline for vessels in any waterway. In fact, the intended track may vary substantially with wind, current, water depth, ship size, ship type, visibility, and a number of other factors including arbitrary choices by the ship master or pilot.

-Given that an environmental, human or mechanical cause for deviation from some intended track occurs, is there any empirical, physical or logical principle which constrains its magnitude to be more often small than large (within the physical limits, of course)? The best hope would be that constant vigilance results in prompt detection of any deviation and that excellent passage planning has provided a ready correction for any contingency. While these goals should certainly be pursued, available evidence indicates that such goals have not been reached in shipping or in most other fields oif endeavor.[18]

3.2.2 Hazard Analysis Approaches

In a study of the risks and hazards of navigational approaches to the then-planned (now operational) Louisiana Offshore Oil Port (LOOP) in the Gulf of Mexico, relatively little of the effort was devoted to risk analysis. The major reason was that the computation of risk normally provides little or no information on how best to manage that risk. A credible statistical estimate that the risk (of oil spills in this case) is significant constitutes sufficient reason to refocus analysis on the most suitable and feasible ways to manage that risk. That, in turn, usually involves a qualitative analysis of the specific nature of the hazards.

To understand offshore navigational dangers, several analytic approaches were taken. First, general trade routes of the vessels were laid out. Recorded hazards were compiled from published references: charts, Sailing Directions and Coast Pilots. Analysts rode vessels in appropriate coastal passages and visited a similar monobuoy port. Discussions with ships officers, pilots and port authorities were productive. All available accident data for the area of interest were compiled and analyzed. A series of "fault trees" (logical hazard diagrams) were constructed. Finally, all sources of data were combined into a hazard classification scheme.[19] The many hazards could be grouped into two major areas: human factors and severe weather, plus two less major hazards: fixed structures and floating debris. A variety of issues concerning offshore fixed structures and human factors in ship operations were subsequently investigated in a real time ship simulator study discussed in section 5.2.3 of this paper.

4. TOWARD A HUMAN-ORIENTED CONCEPT OF SHIP SAFETY

4.1 The Engineering Disciplinary Approach

There have been numerous observations that, while accident data stress human factors, safety research has tended to focus on engineering solutions in specific disciplines: structural, nuclear, naval architecture, electronics and others. In the ship safety area, this process has been noted quite pointedly by the National Academy of Sciences, as well as by the current author and other individuals.[20,21] Partly as a result of this process, the hardware system tends to become somewhat more reliable than the human system. A great many accidents are then seen as being due to "human error", largely because no "mechanical failure" is observed. This is certainly the case in ship operations.

4.2 The Systems Safety Approach

The more modern approach has been to expand the focus to a "systems safety" approach. In this concept a variety of engineering disciplines are integrated into (hardware) "systems engineering," which is then combined with consideration of operational factors, such as material (or fluid or energy or information) flows, queues, and bottlenecks.[22]

"Human engineering" may or may not be integrated into the system. "Human engineering" considerations, if any, usually include design and layout of dials, displays and controls; anthropometric (body measurement) considerations of body position, reach and required strength; and task analytic issues regarding the layout of work spaces, allocation of tasks to people, skill requirements and training needs. More recently, issues of work-rest cycles, environmental stress (noise, vibration, temperature) and teamwork have been included.

4.3 A Statistical Quality Control Approach

None of these approaches have really addressed the human situation in a manner that would satisfy statistician W. Edwards Deming, one of the fathers of modern industrial quality control and one of the men given special credit for the economic revitalization of Japan after World War II. Dr. Deming has observed that only about fifteen percent of industrial accidents or system failures or product deficiencies are attributable to tangible specific failures of either people or machines. In those cases where the tangible failures occur, it is clear that equipment was poorly designed or maintained or that an individual was unsuited to the job or had received clearly inadequate training or supervision.[23]

Of far greater significance, however, most failures occur because of random variance which is inherent to the functional system itself and should not be blamed on any individual. Nonetheless, there is usually some individual who was "on watch" or who "made the mistake" and therefore can be found to be "at fault." It does seem a little strange to some of us, however, that in many cases such people are not found to be the incompetents but rather operators whose work records and attitudes have been highly regarded by their peers and their supervisors. That does not surprise Dr. Deming at all. In fact, it appears to confirm his concept of the nature of quality and alternatively of failure in the workplace.

In Dr. Deming's concept, variability is inherent in human performance, in the performance of specific pieces of equipment, in the environment and in all engineered systems. Accidents, system failures, and product defects can be eliminated only by narrowing the variability to acceptable tolerances throughout the system and by making the system tolerant of those that remain. It can never be assumed that we understand a complex system function well enough to prescribe or to deduce the tolerance of variability or the means of reducing it. The variability bounds must be determined empirically using certain types of statistical methods.[24,25] Establishing means of reducing the inherent system variability is a highly creative and eclectic process.

The possibility of achieving the accident free (or failure free) system rests on the prior condition of having a managerial framework which utilizes its human (and hardware) resources well. That managerial framework must include clear long range goals, credible commitment to quality of product or service, a receptivity to ideas and inputs from many different sources including its own workers, a working atmosphere which is free of fear, and several other factors. These are difficult, but achievable within the setting of a single industrial corporation.

4.4 A Human-Oriented Approach to Maritime Safety

Maritime safety does not occur within the purview of a single organization. Furthermore, it does not seem either necessary nor feasible to create some monolithic institution to have effective control of all the equipment and people who affect maritime safety even in a specific location. How, then, can society gain effective control of maritime safety so as, for example, to preclude ship collisions with bridges and offshore structures?

The generic question was recently addressed by a committee of maritime executives, labor representatives, researchers, policy analysts, and risk/decision analysts under the auspices of the U. S. National Academy of Sciences.[26] It concluded, in effect, that the only people who can directly prevent ship accidents are: first, ship masters (and mates and pilots) and, second, shoreside ship operations executives and staff. The only way in which anyone else can do any good is by influencing these groups with regard to either their <u>motivation for safety</u> or else their <u>capability to achieve safety</u>!

The point may be understood either in a trivial sense (everybody knows these groups control ship movements) or else in a much more subtle and profound sense. To suggest more clearly the profound sense, it can be stated (although probably not without controversy) that the structural engineer has two functions regarding prevention of ship collisions with bridges and other structures:

-To so design the structures that they are in no danger from ships, and, to the extent this is infeasible -

-To so design the structure and its environs that ship operators are optimally motivated toward, and capable of, passing it safely every time.

The second point includes recognizing, for example, that shipping economics frequently demands large vessels, two way traffic, and minimal delays. Bridges or other structures which accomodate these inherent motivations outside the constraints of prior and independent physical aspects of the local waterway, are necessarily safer (all other factors being equal) than similar structures which do not. Where verssel traffic is hindered beyond some norm, ship operating managers are motivated to encourage some compensating measure on the part of masters or pilots. Even independently of shoreside management, the ingrained professionalism of the skilled mariner includes a certain amount of boldness in the expeditious accomplishment of his duties. This leads to some taking of calculated risks, and those risks, when the other variabilities happen to be unfavorable, lead to accidents.

Even if the second guideline (above) to structural engineers is accepted in the intended spirit, of course, there are many other groups that influence ship safety both favorably and unfavorably: international, national, and local governmental authorities; those who maintain waterways and off-ship navigational installations and services; ship builders and repairers, ship classification societies, and insurers; ship equipment designers and servicers; maritime trade unions and schools; and professional groups or societies in ship design, ship operations, ship ergonomics, ship economics, port design and management, and marine traffic engineering.

5. SIMULATION AND SIMULATORS

5.1 The Real and The Unreal

5.1.1 Physical Reality

At the beginning of this paper, it was suggested that the best means of protecting steel and concrete realities might be the use of structured unrealities. The paradox is intended with all seriousness. A key thesis throughout this paper has been that several kinds of realities are crucial to the prevention of structural damage by ships. Only one kind of reality concerns the physics of structures, ship movements and momentums, impacts, plasticities and elasticities. This may be called the physical reality.

5.1.2 The Reality of Uncertainty

At least as important analytically is the reality of random variability, of uncertainty in ship passages near structures. The major failing of risk analysis has been to treat this variability at too high a level of summarization and to prescribe quite unrealistic properties to the oversimplified models. What is needed is much less deductive prescription and much more inductive description so that we can learn more about the real nature of the uncertainty in ship operations. In short, we need to admit that we are even uncertain about the types and bounds of the uncertainty of ship operations.

5.1.3 Human Reality

An important part of the variability of ship operations is human variability. There are very basic scientific elements of human variability which relate to the design and function of the central nervous system, the psychology of learning and or memory, and to individual and social behavioral patterns conditioned by evolution, by current society and by individually influencial persons and events. This, too, is reality. Of more direct interest is human performance and variability within the specific context of ship operations in restricted waters. Here the human must function as an imperfect controller of an inherently variable system, using variable control processes with time lags and measurement errors, in an environment of informational uncertainty. Both the training and the motivation of the personnel are influenced by a large number of factors, some of which rest in the organization and management of their companies, unions, or pilot associations. Other factors rest in specifics of operational scenarios. For example, does the design of a bridge and the approach to it suggest any concern or appreciation for the demands placed on the people who are somehow expected to get the ship safely by under all conditions of wind, current, visibility, equipment failure, and errors by other people? Such thoughts on the human condition also reflect reality.

5.1.4 The Desirable Unreality of Simulation

Simulations are never fully realistic. Reality is too complex to be modeled. More importantly, we create models in order to escape the full complexity of reality. In a similar vein, we do laboratory experiments by carfully eliminating many variables and attempting to control carefully all but one of those in the experiment (the dependent variable). When we do empirical research, we do not gather data on the full complexity of our subject, but only on specific items of interest which seem amenable to analysis. In fact, that is the essence of analysis - seeking out limited aspects of a problem and examining their interrelationships more precisely than we can do in the real world.

Simulations do represent selected aspects of reality; good simulations do this very well. They can help us to explore various components of ship operations variability under controlled conditions and in safety. Thus, although we see mercifully few instances of real major ship collisions with bridges each year, we can study many thousands of simulated passages and/or collisions per year by simulation.

5.2. Ship Simualtion Studies

5.2.1. General

There have been hundreds of ship simulation studies conducted.[27] Some of them address dangers of capsizing [27], maritime traffic [28,29], economically efficient fleet deployment [30], port design [31] and inland waterway design [32]. Some have been fast time models, their logical control totally embedded within the computer and its programming. Some have been real time models, interfacing with human beings who make some of the control decisions and moves during each simulation "run". Some have modeled ship movements as they would occur under natural forces given the initial control settings; some have incorporated track-following autopilots; others have been optimal control models, capable of determining the "best" track feasible to maximize some specified performance criteria [33]. Some have been used for research; others for training or management. Many of these models could in some sense be used to improve bridge and offshore structural safety. This paper addresses mainly research by the U. S. Coast Guard Office of Research and Development. Hopefully, you will have independent access to a very large amount of excellent simulation elsewhere in the U. S., Europe, and Japan, as well as in a growing number of other maritime regions.

5.2.2. Towboat Simulations

Although various ship motion models have existed for a number of years, their sophistication and capability have been growing especially rapidly in the last few years. Not so many years ago, the computer models correctly described only the motions of a very few ship types for which extensive model testing had been accomplished and then only for movements in deep water (six or more times the vessel's draft) and only for forward movement. Because most ship accidents occur in shallow and restricted waters, this was a largely unsatisfactory capability.

With respect to bridge-vessel collisions, this was especially unsatisfactory due to the larger number of pushtow-bridge collisions than of ship-bridge collisions in the United States. Yet pushtows operate often at quite low speeds, at wide drift angles, in water that is very shallow relative to their depth and often with engines backing while the vessel is moving forward. Such conditions demanded a different approach to modeling than had been common in the case of larger ships.

The first real capability was described in a research report of May 1978.[34] It was immediately followed by an application study on bridge collision incidents. This was a pure physical process model, which directed the towboat as dictated by natural forces and the control settings. It occasionally displayed its current control settings to the simulation operator and asked if different settings were desired before it continued the passage.[35]

The problem with this early simulation was that it left all the real work of simulator experimentation to the operator while allowing him relatively little control or assistance. Within a year, analog-digital converters, controls and displays had been added to create a real time simulator with which an operator could interact more effectively to explore the physical consequences of alternative control strategies.[36]

In order to support fast time simulation research more effectively, numerous hydrodynamicists have developed autopilots (track-following controller programs). The simulation described above has been utilized both as a fast-time, autopilot-controlled simulation and as a real time, human-controlled simulator to investigate the serious problems of passing the Berwick Bay bridges.[37] Additional research is being conducted on the Berwick Bay bridge problem. Refinements of that same simulation capability are now being developed to analyze low water shiphandling problems on the upper Mississippi River.

5.2.3 Tanker and Other Vessel Simulations

It was also found that the slow speed, backing and shallow water capabilities of this model were useful in the analysis of large tanker maneuvers within offshore deep water ports.[38] The combination of fast time and real time simulation capabilities of this and other simulation facilities can support a large variety of bridge and other structural design studies.

The simulations discussed above are mainly oriented to the controllability of the vessel. In some cases, masters or pilots help assess vessel controllability under various conditions, but these people are not themselves the focus of the studies.

5.3 Simulators and Shiphandling Behavior

5.3.1 Distinguishing Characteristics

As contrasted with vessel controllability studies, shiphandling behavioral simulations have two distinguishing characteristics:

-the simulators always have people in the simulator control loop

-the simulators require a sizeable and fairly accurate perspective view to provide suitable cues to the human controller because that individual's perceptual skills are involved in the overall operation just as much as shiphandling knowledge and professional judgment.

These features tend to be important to research studies because the precise methods used by mariners in the conduct of their passages has not been completely, or even largely, documented. It is, therefore, impossible to include all of the appropriate assessments and decision criteria in the logic of any automatic controller.

Key types of behavioral simulator studies have addressed appropriate designs and equipment for ships bridges, the training of vessel crews and pilots, and crucial features of ports in terms of their ease of navigation in a human, "user-friendly" sense (over and above the basic vessel controllability in a given waterway.)[39,40]

5.3.2 Research Into the Selection and Placement of Aids to Navigation

One of the widely applicable lines of research being pursued in the United States is development of guidelines for off-ship aids to navigation. These include buoys, lights, daymarks, ranges, radar beacons and other means to help the mariner to evaluate vessel position, orientation and velocity in the waterway. For centuries, various such devices have been placed by unaided professional judgment. Until recently, it has not been possible to bolster those judgments with scientifically determined guidelines and rationales.

Recent and ongoing simualtor studies are now determining the behavioral effects of alternative types, numbers and placements of aids. It has definitely been determined that some placements can narrow the range of track deviations within a given waterway.[41] Presumably, the pragmatically more effective patterns of aids to navigation provide more complete, timely or reliable information to the mariner than do alternative patterns. Reports on the progress of this research will be issued steadily.

5.3.3 Mariner Training Studies

Another general area in which behavioral simulator studies are making progress is in mariner training. Very distinct and practical gains have been assessed in the training of ship crew teams[42], ship engineers[42,43], and ship pilots[44,45].

This author, with Dr. Thomas J. Hammell and others, has been particularly involved in research into what aspects of simulators, simulator instructors and training technology are most effective in improving mariner performance[46,47]. Two reports are now nearly complete which establish guidelines for the design and conduct of mariner simulator training for both senior mariners and cadets (mariner students). Additional studies in this series are also planned.

5.3.4 Simulators and Navigation Near Offshore Structures

With respect to possible collisions of ships with offshore structures, we have studied navigational approaches to an offshore oil port[48, 49]. One of the noteworthy findings in that research is shown in Figure 3. This is a display of the tracklines selected by current, professional large tanker masters, given a common starting point and simple intructions to proceed safely to the offshore port. The black squares on the chart represent oil rig locations. The parallel lines mark "safety fairways" as described in section 3.1.4 of this paper. Noting the wide variations in navigational strategy employed by these masters and the wide track variance apparent in the majority strategy reinforces the emphasis on uncertainty of ship operations. Any "risk analysis" of this problem which might have laid out a single, representative track and then computed theoretical deviations from that track would have been wide of the mark indeed!

All of the transits depicted were made safely, although one master did comment in retrospect that he had come a little too close to the rigs. All participants agreed that the simulated vessel in this study handled like its real world counterpart. All stated that they had been able to adapt to the simulator so that their responses to the conditions presented were the same as they could be at sea. As a result of this research, recommendations were made regarding port procedures, nautical chart design, and shipboard equipment.

6. CONCLUSIONS

-Vessel operational safety is crucial to preventing ship collisions with bridges and offshore structures.

-Although risk analyses are desirable, it is likely that existing methods underestimate the varieties and magnitudes of uncertainty in ship operations.

-As between physical, systems safety, and human-oriented concepts of vessel operational safety, there are strong reasons to favor the latter. (All of these approaches are nonetheless relevant to safety.)

-Given that vessel operational safety is relevant, a variety of fast time and real time simulation methods can aid in needed assessments of vessel controllability.

-Perspective view vessel simulators can be applied to research and training in a variety of ways which can aid in the human-oriented approach to vessel operational safety.

Facts and opinions stated are the sole responsibility of the author, not the U. S. Coast Guard.

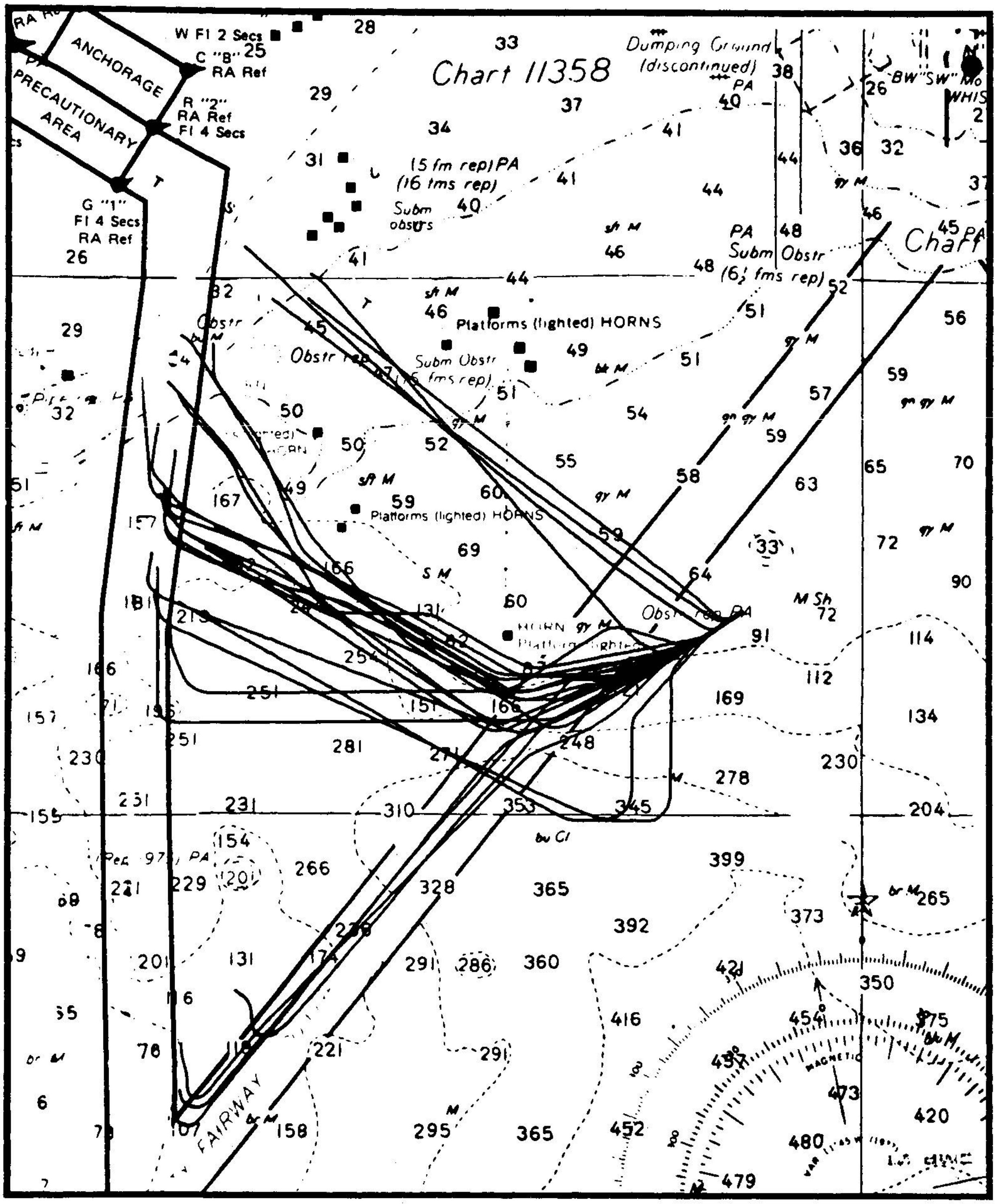

FIGURE 3. INDIVIDUAL SHIP TRACKS DURING THE COASTWISE APPROACH

REFERENCES

1. U. S. Coast Guard Marine Casualty Report, SS AFRICAN NEPTUNE, Brunswick, Georgia, 7 November 1972, USCG/NTSB-MAR-74-4.

2. National Transportation Safety Board (USA), NTSB, Marine Accident Report: U. S. Tankship SS MARINE FLORIDIAN Collision with Benjamin Harrison Memorial Bridge, Hopewell, Virginia, 24 February 1977, NTSB-MAR-78-1.

3. NTSB, Collision of the M/V STUD with the Southern Pacific Railroad Bridge over the Atchafalaya River, Berwick Bay, Louisiana, 1 April 1978, NTSB-MAR-80-5.

4. NTSB, Ramming of the Sunshine Skyway Bridge by the Liberian Bulk Carrier SUMMIT VENTURE, Tampa Bay, Florida, 9 May 1980, NTSB-MAR-81-3.

5. DAYTON, R. B., Analysis of Bridge Collision Incidents, Volume (V) I, National Technical Information Service Number (NTIS) AD-A029 034 and V. II, December, 1976, NTIS AD A036 732.

6. SMITH, J. and others, Task Analysis Report Relative to Vessel Collisions, Rammings and Groundings, December 1976, V. I - NTIS AD A037 316, V. II - NTIS AD A037 317, V. III - NTIS AD A037 442.

7. PARAMORE, B. and others, Human and Physical Factors Affecting Collisions, Rammings and Groundings on Western Rivers and Gulf Intracoastal Waterways, January 1979, NTIS AD A074 290.

8. PARAMORE, B. and others, Study of Task Performance Problems in Reports of Collisions, Rammings and Groundings in Harbors and Entrances, March 1979, NTIS AD A071 058.

9. U. S. Coast Guard, Bridge Administration Operating Program Plan: Fiscal Years 1983-92, p. 1.

10. U. S. Congress, Committee on Commerce, Science and Transportation, The U. S. Coast Guard, 1 March 1982.

11. CORDELL, C. C. and NUTTER, R. V., Shiphandling and Shiphandling Training; Training Analysis and Evaluation Group (TAEG) Naval Training Equipment Center, December, 1976.

12. NTSB, Annual Reports to Congress, 1977, 1978, 1979, and 1980.

13. BUTT, J. A., Recent Developments in Navigation Training, in Safe Navigation Symposium Proceedings, Oil Companies International Marine Forum, Washington, D. C., January 1978.

14. Karlsen, J. E. and S. Kristiansen, Cause Relationships of Collisions and Groundings: Statistical Survey of Collisions and Groundings for Norwegian Ships for the Period 1970-78, Det Norske Veritas Research Division, Oslo, March, 1980.

15. Maritime Transportation Research Board (MTRB), Human Error in Merchant Marine Safety, National Academy of Science (US), January 1978.

16. NTSB, U. S. Tankship SS TEXACO NORTH DAKOTA and Artifical Island EI-361-A Collision and Fire, Gulf of Mexico, 21 August 1980, NTSB-MAR-81-4.

17. GARDENIER, J. S., "Beyond Statistics to Risk Management", Presentation at the American Association for the Advancement of Science Annual Meeting, Washington, D. C., 3-8 January 1982.

18. RASMUSSEN, J. and ROUSE, W. B. (editors), Human Detection and Diagnosis of System Failures, Plenum Press, London and New York, 1981.

19. FARAGHER, W. E. and others, Deepwater Port Approach/Exit Hazard and Risk Assessment, February 1979, NTIS AD A074 529.

20. MTRB, Research Needs to Reduce Maritime Collisions, Rammings and Groundings, National Academy of Science, 1977.

21. GARDENIER, J. S., Toward a Science of Marine Safety, in C. C. GLANSDORP (ed.), Marine Traffic Systems, Maritiem Institut, The Netherlands, 1976. Portions reprinted in Schiff und Hafen, July 1976.

22. HAMMER, W., Handbook of System and Product Safety, Prentice-Hall, Englewood Cliffs, New Jersey, 1972.

23. DEMING, W. E., Management of Statistical Techniques for Quality and Productivity, 1981.

24. SHEWHART, W. A., The Economic Control of Quality of Manufactured Product, American Society for Quality Control, 1980.

25. ISHIKAWA, K., Guide to Quality Control, Asian Productivity Organization, Tokyo, 1976.

26. MTRB, Marine Safety: A New Orientation, 1982.

27. FALLON, W. J. and others, Model Tests and Numerical Simulation of Ship Capsizing in Following Seas, January, 1980, NTIS AD A100 306.

28. GRASSLER, E. and MEADER, N., Vessel Traffic Services Traffic Management Summary Report, 2 July 1981, NTIS AD A106 376.

29. NOE, P. P. and VELDHUYZEN, W., The Use of Simulation Techniques as a Tool for Vessel Traffic Management, TNO Institute for Mechanical Constructions, Delft, The Netherlands, March, 1981.

30. KAPLAN, M. and others, Scheduling Product Distribution by Tanker, in Proceedings of the 1981 Summer Computer Simulation Conference, July, 1981.

31. COOK, R. C., Evaluation of Deep Draft Coastal Port Designs, in Proceedings of the Fourth Annual CAORF Symposium, Kings Point, New York, 29-30 September 1980.

32. SCHUFFEL, H., Simulator Study on the Design of Inland Waterways, in Proceedings of the Fifth Ship Control Systems Symposium, Annapolis, Maryland, 30 October - 3 November 1978.

33. WEINER, L. B. and MOON, A., Vessel Navigation System Simulation, V. I-III, January, 1982.

34. MILLER, E. R., The Prediction of River Tow Maneuvering Performance, May 1978, NTIS AD A805 9408.

35. PETRIE, G. L., Simulation of Bridge Collision Incidents Involving Inland Waterway Tows, June 1978.

36. VAN DYKE, P. and MILLER, E. R., Towboat Maneuvering Simulator, V. I-III, May 1979.

37. VAN DYKE, P., An Analysis of the Berwick Bay Bridge Passage, June 1980, NTIS AD A093 092.

38. BARR, R. A. and others, Maneuvering of Tankers at Deep Water Ports, February, 1981.

39. Nautical Institute (UK), MARSIM 78: First International Conference on Marine Simulation, Southampton, UK, 5-8 September 1978.

40. CAORF, MARSIM 81: Second International Conference on Marine Simulation, Kings Point, New York, 1-5 June 1981.

41. SMITH, M., BERTSCHE, W. R. and SCHROEDER, K. R., The Use of Real Time Man-In-The-Loop Simulation to Measure the Effectiveness of Aids to Navigation Configurations, in Proceedings of OCEANS 80, Marine Technology Society, Washington, D. C., October 1980.

42. MILLAR, I. C. and REYNOLDS, J., Marine Simulator Developments in the United Kingdom, in MARSIM 81.

43. JASPERS, B. W., Training of Ship Engineers, MARSIM 81.

44. WILMS, O., The Training of Pilots on a Shiphandling Simulator, MARSIM 81.

45. HUSSEM, J. and DeBOER. C., Seven Years Experience With Simulator Training of VLCC Pilots in the Netherlands, MARSIM 81.

46. GARDENIER, J. S. and HAMMELL, T. J., Shiphandling Simulator Standards and Training Techniques, MARSIM 81.

47. HAMMELL, T. J., The Training Device is More Than a Simulator, MARSIM 81.

48. COOK, R. C., MARINO, K. L., and COOPER, R. B., A Simulator Study of Deepwater Port Shiphandling and Navigation Problems in Poor Visibility, January 1981, NTIS AD A100 656.

49. GARDENIER, J. S., Navigational Safety Approaching Offshore Deepwater Ports, in Proceedings of the 1981 Oil Spill Conference, Atlanta, Georgia, 2-5 March 1981.

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