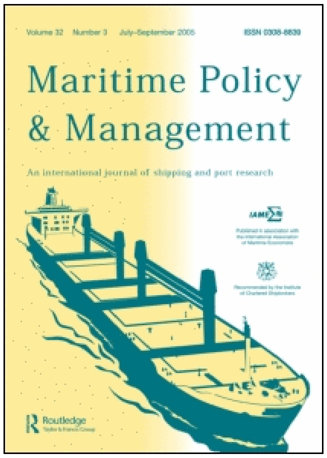

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A human factors systems approach to examining oil spills in tankbarge operations: analysis and reappraisal of management policies

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An important problem in the US maritime industry is the large number of oil spills that occur as a result of oil transfer operations involving tankbarges. Recently, the US Coast Guard initiated a new programme entitled Prevention Through People that represents a concerted effort towards preventing human errors leading to casualities and oil spills. The purpose of the study reported in this paper was to explore tankbarge oil transfer operations from the standpoint of regulatory, management, and operational perspectives in order to determine the likelihood that this new initiative will indeed result in a better understanding of the causal basis for human error in these operations and, more generally, in the maritime industry. The results of this novel study are discussed and summarized in terms of four broad classes of recommendations.

1. Introduction

Between 1986 and 1993 there were 55 998 oil spills in US marine waters attributable to maritime sources. According to the United States Coast Guard (USCG), 80% of these accidents were attributable to human error [1]. However, in marked contrast to high-risk industries such as commercial aviation [2] and nuclear power [3], for which programmes have been established to research, analyse, and monitor human factors problems related to human reliability, the maritime industry in the US has only very recently begun to recognize the importance of a human factors perspective to risk analysis and prevention. As noted in [4], human factors approaches such as human reliabilty analysis (HRA) represent the most effective approach to oil spill prevention. In general, this approach emphasizes a systems model that integrates organizational, training, and design factors with knowledge concerning human capabilities and limitations associated with processing information and making decisions.

From a policy standpoint, the Prevention Through People (PTP) programme recently initiated by the USCG [3] represents an attempt to apply a human factors approach to prevent human errors in the maritime industry. The PTP initiative adopts the following four objectives: (1) to detect, assess, and predict human error in high-risk maritime operations such as towing tankship/barges, fishing, offshore, and passenger operations; (2) to use a system's perspective to perform root-cause analyses in maritime accidents and casualities with an emphasis on loss of life, injury, and pollution; (3) to develop and implement preventative measures collaboratively with industry, researchers, and governmental agencies in order to reduce casualities stemming from human error; and (4) to collectively share safe practices, lessons-

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learned, casuality data, and analyses among the maritime industry and governmental agencies.

The catalyst for addressing maritime accidents and oil spills was the *Exxon Valdez* grounding in Prince William Sound, Alaska, on 24 March 1989 [5] and the resultant Oil Pollution Act of 1990 (OPA 90) [6]. This act focuses on the prevention, mitigation, and penalization of oil spills, while the PTP initiative primarily stresses the human element and errors in the high risk areas of the martime industry. Prior to OPA 90, oil spills were almost an accepted hazard of the waterborne transportation of chemical and petroleum products.

As identified in the PTP initiative, the transport and transfer of petroleum products by tank vessels was placed in the category of 'high-risk' activities, where human error prevails and continues to persist. Within this category of high-risk operations, the 'topping-off' of tank vessels was identified by the USCG as the most critical operation [7]. In additon, poor human factors in the design of equipment and procedures was cited as a major contributing factor in the spillage of oil [8]. Prior to 1990, the USCG's approach to both human error and equipment failure was via regulation (e.g. engineering solutions such as specification of hull plating thickness) and enforcement tactics. While this emphasis on engineering solutions has been successful in reducing equipment failures, it has failed to address the problem of human error [3]. Consequently, the USCG has indicated that a change in culture is necessary if the maritime industry is to benefit from a new approach to the investigation and prevention of human error. Hence, there is a recognized need to move away from the traditional perspectives to safety that have characterized the maritime as well as other industries. Such perspectives generally attribute accidents involving humans to the violation of procedures. This practice, in turn, often results in the generation of 'blame-cultures' [9].

In recent years, there has been a growing tendency in high-risk industries to emphasize a qualitative perspective to HRA [9, 10]. Some of the benefits of this approach to HRA is a better understanding of the causes of human errors and violations as well as an anticipation of their occurrences, allowing the suggestion of design interventions that could prevent or minimize the adverse consequences arising from such behaviours. Another benefit of this approach is that it naturally lends itself to the design of information systems for effectively managing and continuously improving the safety of the maritime system, in line with current Total Quality Management (TQM) principles [11, 12].

This paper reports on a study examining human error in tankbarge oil transfers. The primary purpose of the study was to evaluate the applicability of the qualitative HRA perspective to these marine operations, and the extent to which the mechanisms and information needed to apply this methodology effectively are currently in place. In pursuing this goal, the study provides a basis for examining potential shortcomings of the PTP programme, and for understanding the necessary changes in policy required for maximizing the chances of success of this programme.

The focus of this study was on oil spills arising from the loading and discharging operation associated with tankbarges. Although major oil spills usually attract the most attention by the public, they are, however, very infrequent. In contrast, the spills from tankbarges are usually minor but occur with greater frequency, and represent a significant concern with respect to the continual impact on the environment and allocation of resources for their investigation and cleanup. This is especially relevant when one considers that 80% of US petroleum products are transported by tankbarges and that most of the tankbarge spills occur during transfer operations and not from collisions or groundings [13]. Moreover, the ability to analyse and understand scenarios associated with tankbarge operations which may result in oil spills can go a long way towards helping to understand the underlying causes of human error across many other maritime operations.

2. Methodology

Due to the exploratory nature of this study, and especially in view of the lack of previous research in tankbarge oil spills, a variety of methods were used to collect data. These included: (1) analyses of procedures, checklists, and data collection methods associated with oil transfer operations; (2) interviews with individuals from the USCG, marine environmental services, tankbarge corporations, and tankermen; (3) analysis of tankermen test requirements; (4) field studies of oil transfer operations; (5) analysis of the USCG's Marine Spill Casualty Incident Report (MCIR) system database to study previous tankbarge oil spills over a 2 year period; (6) analysis of the USCG's transfer inspection citation database; and (7) anecdotal evidence.

During a familiarization period that preceded the data collection and analysis, the authors had the opportunity to become more knowledgeable in the relevant maritime operations. This knowledge was derived through exposure to a USCG approved oil tanker training school's course and generic oil transfer simulator, selected handbooks on the subject of maritime oil transportation and transfer operations [e.g. 14–16], and several unstructured field observations. The latter enabled subsequent field observations to be more focused and also provided a better understanding of the environment encompassing oil transfer operations. In addition, one of the investigators had extensive previous maritime experience which was especially beneficial with respect to understanding domain specific language during tankbarge operations.

2.1. *Field observations*

Following the familiarization phase, a 'field observation form' was developed for guiding the collection of field observations. The basis for the development of this form was a task analysis [17] of the oil transfer procedure. This analysis, in turn, was based on interviews with students and the instructor of the oil tanker training school course, observations of simulated transfers, and task descriptions in the literature. Five field observations were conducted on the southeastern coast of Florida; four of these occurred within the Port of Miami and one was conducted at Port Everglades in Fort Lauderdale. Four of the observations were conducted from the short-side terminal and one observation was conducted on board a ship-to-ship transfer. The observations were designed to be as unobtrustive as possible and no indication was given as to their purpose. Difficulties were often encountered in securing permission to observe the transfer operations due to the novelty of having researchers aboard tankbarges and the hazards involved in most large port operations. Furthermore, permission was generally required from several entities including the Port Authority, one or more tankbarge companies, and the Terminal Authority. These difficulties were often compounded by scheduling problems resulting from delays or cancellations of oil transfers, inclement weather, equipment breakdowns, and tankbarge rerouting.

Table 1. Tankbarge oil spill categories and supplemental information.

1. Tank monitoring (overflow)	1. Hull defect or penetration	1. Spill amount (in gallons)
2. Hose connection or disconnection	2. Valve or fitting failure	2. Cleanup effort (yes or no)
3. Valve setup or alignment	3. Gasket failure	3. Oil recovered, if applicable (in gallons)
4. Loose or unblanked flange	4. Pipe or hose failure	4. Time lapse from spill event to USCG notification (in minutes)
5. Maintenance	5. Packing gland or seal failure	5. On-scene investigation time (in hours)
6. Drip pan monitoring (overflow)	6. Pump failure	6. Administrative time (in hours)
7. Mooring monitoring	7. Other	7. Training time (in hours)
8. Other		8. Travel to and from scene (in hours)
		9. Spill investigation effort (on-scene investigation time + administrative time + training time)
		10. Time of spill event (24 hour clock)
		11. Narrative of spill event either by witnesses or investigative personnel

2.2. *The MCIR database*

The Marine Spill Casuality Incident Report (MCIR) system is a computer-based storage and retrieval reporting program which records oil spills and other maritime incidents such as collisions and groundings. From this database, the USCG provided a random sample of 255 US flagged tankbarge oil spills which occurred during ship-to-ship, ship-to-shore, and shore-to-ship oil transfers. This sample encompassed a 2-year period and involved only US navigable waterways. An MCIR report consists of a cover page that includes a brief synopsis of the spill as well as a checklist for supplemental case reports such as witness lists, human factors supplements, and statements. For this study, each MCIR oil spill report was initially assigned into one of two categories: human error or equipment failure. However, given that many of the cover page synopses provided little, if any, information related to human error, and more generally, to the specific cause of the spill, the supplemental reports were frequently retrieved, which proved to be an arduous task. With this information, the human error and equipment failure categories were further categorized, as indicated in table 1. Information on other variables related to the oil spill and the post event investigative efforts were also collected.

2.3. *Transfer violation citations*

The Code of Federal Regulations stipulates that the Coast Guard's Captain of the Port (COTP) must be notified in advance of any transfer operations within the District's operational area (these individuals stated that they attempt at least one spot inspection per day). This allows the Coast Guard to remain cognizant of hazardous operations and to perform spot inspections of transfer procedures. If the inspection reveals any violations of the regulations, then a citation with a possible monetary fine is imposed and kept on record unless contested and judged not guilty. In this study, a random sample of 12 transfer violation citations were selected from USCG records. Examples of actions constituting a violation include: failure to post oil transfer procedures, failure to maintain a fixed containment area, absence of a Person in Charge (PIC), and insufficient personnel for the transfer operation.

2.4. *Tankerman training and licensing*

Tankermen are required on all US flagged tank vessels (ships and barges) that carry oil or hazardous chemicals in bulk. In this study, the requirements for licensing of tankermen, including the written test materials, are examined further in order to assess the possible contribution of the licensing procedure to human error in oil spill hazards.

2.5. *Interviews*

A total of 22 in-depth interviews were conducted with personnel who serve a variety of functions in the transportation, transfer, and cleanup of petroleum products. These 22 interviewees were classified as follows: two licensed tankermen, two terminal supervisors, two oil spill responders, nine USCG personnel, and three oil transfer school instructors and administrators. Questions were both structured and open-ended, with the responses used primarily to provide contextual support for other data [18]. The interviews were conducted face-to-face and, with the exception of the tankermen who were interviewed in the field, the interviews were conducted in the respondent's location of employment. All interviewees were informed of the purpose of the study and were assured that their responses would be confidential. Where appropriate, specific tasks and incidents were discussed in order to solicit professional opinions.

3. Results and discussion

Due to the relatively large amount of data collected, especially from interviews, accident reports, and field observations, only a sample of the results will be presented. The essence of the results of this study will be summarized in the recommendations that follow.

3.1. *MCIR database analysis*

A Chi-Square test was performed to test the hypothesis that there was no difference between the two major categories (human error and equipment failure) of causation of oil transfer spills (table 1). The interest in this hypothesis was based on the presumption by the USCG [3] that 80% of maritime accidents, including oil spills, can be attributed *directly* (i.e. not including more indirect errors such as mistakes in ship or equipment design) to human error. Results indicated that there were no significant differences between these two categories, $\chi\ (1, n = 254) = 0.567$, $p = 0.452$. In fact, tankbarge oil spills were found to be approximately equally distributed between these two factors (figures 1 and 2). Furthermore, statitistical analysis revealed that there was no significant difference in the investigative time the USCG allocates to oil spills stemming from these two causes [19]. Interestingly, all but two of the interviewees failed to even mention equipment failure as a significant concern in the causation of spills, a finding which suggests that, despite claims to the contrary, a 'blame culture' continues to dominate the thinking of many maritime administrators. Not surprisingly, it was the two USCG pollution investigators who had extensive field experience in spill investigations who believed that spill causation was equally attributable to human error and equipment failure.

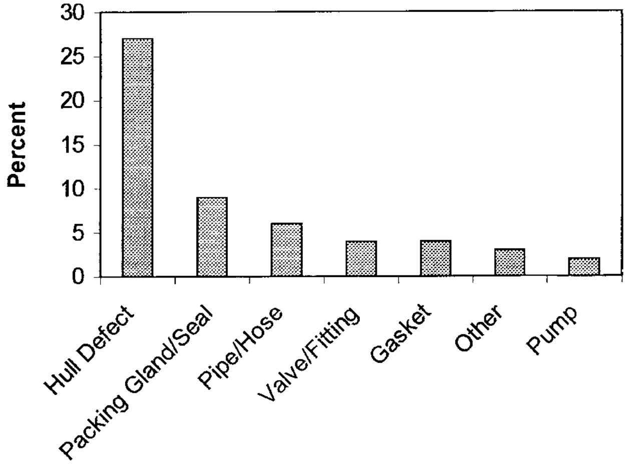

Figure 1. Spills by equipment category.

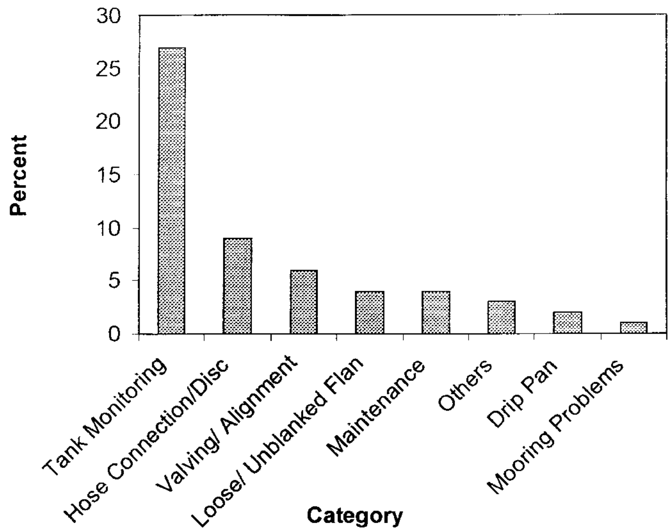

Figure 2. Spills by human error category.

Of the 255 spill reports collected, only 38 included some type of narrative and, of these, only 19 provided any additional information to that contained in the MCIR cover page. Moreover, only six of the narratives attempted to explain the causes or the chain of events that led to the spill. Most of the narrative supplements simply reiterated the basic facts, and lacked the contextual details needed to conduct a root cause analysis. It was also apparent that, without a model or framework to performing a HRA, there is no means for integrating the findings of these reports into an information system that can use this knowledge in a systematic way for obtaining a better understanding of the deeper causes of the problem. For example, in one relatively informative narrative supplement, lack of communication appeared to be a factor in the spill:

> 'The receiving line at the facility is equipped with an air fitting that when utilized is designed to apply air back through the transfer line to assist in clearing the hose of residual product. This procedure was not done. The tankerman assumed that the person in charge ashore had applied air to the line. The person in charge ashore assumed that if the tankerman wanted air applied to the line he would have asked for it. Both parties have been advised to review their transfer procedures and to be specific when communicating.'

Given that this was not the first time these workers were involved in this operation, other work-related factors very likely contributed to the assumptions made by these workers. An analysis of the work contexts as a component of a HRA would be necessary to reveal these contributory factors. When the details of such an analysis are linked to an appropriately designed marine information system, patterns may be revealed that can point to many similar types of 'faulty assumptions' that are made, ultimately leading to error reduction recommendations or design interventions that can effectively address the problem.

3.2. *Transfer violation citations*

In principle, oil transfer violation citations could supply valuable information concerning underlying problems and 'near miss' data. Unfortunately, the citations served primarily as a penalization rather than a learning experience. These citations encompass an enormous amount of information regarding the vulnerabilities and breach of procedures within the oil transfer process, and thus could be used to gain insights into the lapses and mistakes (i.e. human errors) that occur in the field. However, the documentation and processing of the citations would have to be improved drastically in order for their information to be integrated effectively into the marine information system.

3.3. *Tankerman training and licensing*

As substantiated by the interviews, the requirements for licensing of tankermen were found to be deficient in that they set a minimal rather than a maximal standard. For example, the tankerman multiple choice written examination appears to serve merely to flag candidates who are incompetent rather than to measure skill level. Very little emphasis is given to the development of problem solving skills and good knowledge bases. This emphasis is essential if tankermen are to have good mental models associated with oil transfer operations. Otherwise, tankermen are less likely to anticipate problems or be capable of dealing with a variety of contingencies that may arise during these operations. In line with other high-risk industries, there is a clear need for making simulator training available for tankermen to ensure that they develop the appropriate skills necessary for minimizing the occurrence of spill events and for maximizing their ability to contain the spills after their occurrence.

3.4. *Interviews*

The interviewees' responses were briefly summarized under four headings: (1) training and certification, (2) oil transfer tasks and spill causation, (3) federal regulations, and (4) the marine information system.

3.4.1. *Training and certification.* With the exception of the tankermen, the respondents felt that the training and licensing process was deficient. This attitude is reflected in the following response:

> 'The candidates study to pass the multiple-choice exam. Consequently, they do not develop rudimentary skills necessary for handling contingencies and anomalies in the transfer process. Previously, the exam was structured around essay questions and probed a much deeper knowledge base than the present exam.'

In contrast, tankermens' responses indicated that they felt that the certification process could not mirror the skills necessary to transfer oil, and that it was through on-the-job training that they acquired the necessary knowledge.

3.4.2. *Oil transfer tasks and spill causation.* All respondents characterized the majority of oil transfer operations as routine and monotonous, and identified the connection/disconnection and 'topping off' steps as the most critical in terms of the likelihood (risk) of oil spill occurrences. Overall, respondents felt that fatigue resulting from long work schedules contributed to many of the oil spill incidents. For example, a tankerman in Fort Lauderdale who had just arrived from a long passage from Houston, Texas stated: 'We just completed a 5 day tow in some rough weather and here we are at 06:00 ready to unload for probably 12 hours'. In general, most of the respondents attributed oil spills to carelessness, not following procedures, and inattention at the 'topping-off' point. The USCG respondents emphasized complacency and the failure to follow posted procedures as the primary causes of spills. A USCG Pollution Investigator stated: 'Probably the second most common cause of spills is related to people ignoring procedures or taking short cuts, especially at times such as "topping-off" at too high a rate of flow'. Several tankermen, however, attributed their complacency to fatigue and erratic schedules. An oil transfer Terminal Supervisor felt that translating the unloading plan into a 'flow model' constituted the most difficult task associated with oil transfer operations, especially in view of last-minute changes that often occur in discharge plans. This concern is very much related to deficiencies that have been noted in the training and licensing of tankermen, and the lack of an adequate mental model of oil flow.

3.4.3. *Regulatory issues.* There were strong differences in opinion among some of the respondents about the effectiveness of regulations to curtail oil spills and incidents. For example, oil transfer industry executives felt that there were enough regulations, and that research efforts in this area would likely lead to over-regulation of the oil transfer industry. One supervisor from the oil industry felt that the USCG tended to have a 'reactionary' response to the maritime oil industry, especially in light of the *Exxon Valdez* spill, and stated:

> 'The most difficult regulatory problem I encounter is the lack of standard formal procedures between districts and among the captains of the ports ... each [of the captains] will have their own idea on how to interpret and apply federal regulations ... We are a conscientious company and careful in what we do, but on occasion spills occur; let's take it in stride and learn from it and not play the blame game.'

The actual transfer personnel felt much more strongly about the need for regulations. However, their concerns were with the focus of the regulations. Specifically, many of these respondents, and especially the USCG officers, felt that the regulations were overly biased in technical and mechanical matters. As one USCG officer noted: 'I feel that we've done very well in regulating the technical aspects of oil transfers, but we've neglected the human element in the process and in the maritime industry as a whole'.

3.4.4. *The marine information system.* Personnel affiliated with the USCG Marine Safety Office noted that there were serious deficiencies associated with the current information system used by the USCG for handling marine safety problems, including casualities and oil spills. A new 'module-based' information system, under development, is intended to correct many of these deficiencies through the use of a relational (as opposed to a hierarchical) database design as well as other design features. Such a system could provide a causal basis for such accidents. However, there were still many concerns. A Senior Casuality Response Officer for the USCG Marine Safety Office admitted that there was a need for the information system to be driven by a model or modelling framework that could allow users to gain a better understanding of the causes of accidents, and also to enable data on near misses or close calls to be evaluated in order to better anticipate safety problems.

3.5. *Observations and anecdotal evidence*

Given that most field observations result in 'normal data' that seldom reveal human or equipment failures, the primary purpose of the field observations was to analyse work contexts from the standpoint of their *dispositions* for oil spill incidents. A number of work context factors conducive to human error were identified. These factors included: the transition from monotonous tasks to highly intensive tasks such as initial setup and 'topping-off'; external factors that preceeded oil transfer operations such as previous work shifts, night operations under conditions of nominal lighting, previous time in transit, and weather conditions subjected to; situational awareness, especially in the breadth and level of attention given to equipment factors prior to, during, and following transfer operations; environmental noise that could contribute to communication problems, including issues related to language comprehension.

Several examples of anecdotal evidence were collected in this study [20]. Anecdotal evidence is typically in the form of informal discourses concerning operations in which problems such as near failures occurred. These types of reports were found to contain valuable forms of data that can provide indications of unsafe conditions, procedures, and operations that can contribute to potential accidents. This type of evidence also allows the oil spill analyst to consider contextual information that is typically absent in most of the marine databases.

4. Summary and recommendations

The major recommendations of this study are discussed in terms of the following four broad categories. The first category concerns the need for developing and implementing a human reliability analysis model in support of a marine information system. In the Prevention Through People (PTP) report [3], three shortfalls in current marine safety data analysis capabilities are noted: (1) the absence of adequate human error causal data; (2) the absence of a standard human error taxonomy or root cause investigation method; and (3) the lack of consideration of near-miss events. Clearly, there is a need to develop a data collection system that incorporates near miss data and anecdotal evidence. However, the current emphasis in the PTP programme on developing a *generic* human error taxonomy for data collection will likely fail to capture, let alone be sufficiently sensitive to, the issues of human information processing, error tendencies and, in general, the various factors comprising marine work contexts that conspire to produce hazardous conditions and accidents.

This study strongly suggests that, without the development and implementation of a human reliability analysis model that is tailored to marine system contexts, major shortfalls will remain in the ability to anticipate conditions conducive to human error and to understand how accidents occur. The incorporation of a human and system reliability modelling approach into the oil spill data collection and analysis process also has the advantage of: (1) enabling anticipation of problems in work situations that are seemingly innocuous, such as the routine daily actions of tankermen; and (2) analysing the basis for procedural violations, which in many high-risk work environments have become an even more serious problem than human error. It would also maximize the utilization of near-miss data and anecdotal evidence. Finally, by virtue of the model's inherent capability for being continuously fine-tuned [9], the use of this approach for guiding the collection and analysis of marine data on oil spills is consistent with a Total Quality Management (TQM) perspective [11, 12]. Such programmes promote feedback channels from workers to management (e.g. by allowing workers to present anecdotal evidence), and typically result in improved work cultures. However, personnel who collect data on oil spills, as well as personnel who are expected to manage the marine database, would have to be trained on the use of such a model.

There is also much that can be learned from other industries and their approaches to data collection, error management, and intervention strategies. Hence, mechanisms should be implemented for cultivating a dialogue between the marine industry and these other industries on the above issues. For example, with respect to the implementation of a near-miss reporting system, the Aviation Safety Reporting System (ASRS) operated by NASA [20] is an excellent example of such a system, and represents an opportunity for technology transfer that could significantly impact error prevention by enabling analysts to spot trends and conditions which may be developed prior to an accident.

The second major category of recommendations address the training and licensing of tankermen. The current emphasis on establishing a minimal rather than a maximal standard provides little in the way of developing problem solving skills, knowledge base supplementation, and contingency planning. Although on-the-job training is necessary, it should not be a substitute for a rigorous qualification and licensing programme. For example, commercial airline crews must be able to describe and actually demonstrate operational parameters, systems, and anomalies in their aircraft type in order to receive initial certification and subsequent renewals. This type of rigor in training is lacking not only with respect to tankermen, but more generally to the marine industry. Presently, the USCG plans to overhaul the process of certification of all maritime personnel, including tankermen. However, without adequate training, tankermen are not likely to have the knowledge and insight to anticipate problems prior to their manifestation (e.g. in developing situational awareness of equipment maintenance problems), let alone deal with the variety of contingencies that may arise in oil transfer operations. It is important that the regulatory agencies develop and benchmark a comprehensive training programme for tankermen which emphasizes such proficiency. One method of training that the maritime industry should consider for personnel such as tankermen is simulator training. Many industries such as aviation and nuclear power have embraced the use of simulators, especially for handling contingencies and for instances where workers need to interact with new equipment.

The third category of recommendations concerns the oil spill investigative process. In principle, the purpose of a pollution investigation is to uncover the root-cause of the spill and, hopefully, to apply the lessons learned to prevent similar occurrences. Currently, the focus is on identifying the physical source of the spill and the responsible party, and assessing remedial measures and monetary fines. The investigative process rarely proceeds to a deeper level of root-cause analysis and to documenting lessons learned. As evident by the multitudes (upwards of 60 000) of spills in the US marine waters in the past decade [3], very few lessons appeared to have been learned from either the investigations conducted or from the marine databases. The problem is not with the investigators *per se* but, as this study determined, with the training and methodological tools they are provided with, in order to collect field data and deduce causality. Human factors training that would enable investigators to identify the various demands placed on marine workers and their abilities for meeting those demands, and incorporation of a human and systems reliability model to understand how these demands can translate into errors and violations, are needed to significantly improve the efficiency of the investigative process.

It is also important that pollution investigators become more familiar with actual oil transfer operations over and beyond their role in responding to incidents and conducting spot checks. This knowledge would further support their use of a human reliability model by enabling them to better understand work contexts, and ultimately contribute to their ability to interact more effectively with a marine information system. In general, the investigator needs to be able to identify information and actions that, when evaluated across a broad spectrum of oil transfer contexts, can potentially contribute to a condition conducive to error or to a chain of events leading to an accident. This entails having an understanding of the various phases of the overall oil transfer operation. For example, certain phases of the operation are more vulnerable to distractions or interruptions that could occur, given the omissions and incorrect actions (e.g. slips and lapses) that these events induce. Obtaining this type of knowledge requires developing a protocol for conducting field observations; such a protocol is currently non-existing.

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