Simulation and Modeling: A Tool for Public Policy Research

Capt. Anthony Patterson, Mr. Leslie G. O Reilly
Fisheries and Marine Institute of Memorial University of Newfoundland
PO Box 4920, St. John s, NL, A1C 5R3, CANADA
anthony.patterson@mi.mun.ca leslie.oreilly@mi.mun.ca

ABSTRACT

Within Canada, the Federal Government has initiated a discussion on the application of the precautionary approach in a number of high risk areas, including marine transportation. The authors believe that the application of the precautionary approach in the maritime sector implies a more rigorous risk assessment for policy initiatives than is currently required. Given the fundamental changes occurring in the Canadian maritime regulatory system; the rapid proliferation of new technology, and the desire to expand shipping activities into remote and pristine areas, the scientific and academic communities can play a vital role in guiding policy-makers in their application of the precautionary approach to shipping.

Over the past 30 years there has been a shift in the public perception on the importance of safety, environmental protection, and - more recently - security to society. As regulators and shipping interests attempt to create a safer, more environmentally friendly and secure maritime transportation sector, they have been confronted with the fact that human error is the main cause of shipping incidents. If it is accepted that there is a desire to improve the maritime transportation system, and that human factors represent one of the key weaknesses in the system, then there is a need to improve the capabilities to deal with human factor issues. Simulation is a method to identify, quantify, and modify risky behaviors in transportation systems, and represents a critical tool in the evolution of public policy in the maritime sector.

The authors propose that the academic, scientific, regulatory, and corporate communities begin a collaborative effort to address human factors issues using the existing maritime simulation capabilities in Canada. The authors further propose that a modest investment be made to develop modeling and simulation capabilities that will permit more advanced studies to be conducted in the future.

1. Introduction

In September 2001, the Government of Canada published a discussion document entitled *A Canadian Perspective on the Precautionary Approach/Principle*[i]. The intent of the document is to stimulate discussion on the application of the precautionary approach[*] in the development of public policy initiatives.

The Government of Canada has developed their concept of the precautionary approach from Principle 15 of the *1992 Rio Declaration on Environment and Development*:

> *In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.*

Within Canada, the Federal government suggests that Principle 15 of the Rio Declaration be expanded to include science-based programs of health and safety, the environment and natural resources conservation, both domestically and internationally . While the Federal Government has not specifically identified the Programs to which the precautionary approach would apply, the list of Departments contributing to the development of the discussion document includes Transport Canada, which acts as the Maritime Administration for Canada.

[*] The Canadian discussion document equates the terms precautionary approach and precautionary principle . In this document we will use only use the term precautionary approach for simplicity.

The discussion paper circulated by the Federal Government contains a comprehensive overview of the precautionary approach of which we will outline 2 aspects. The first aspect will be the rationale for extending the application of the precautionary approach to non-environmental areas. The second will be the guiding principles for the application of the precautionary approach.

The government discussion document indicates that the fundamental reasons for a broad application of the precautionary approach are legal, political, and economic. Legally, the government believes that the application of the precautionary approach will help to help demonstrate due diligence related to decisions that it makes, especially in the areas of human health, safety, and the environment. From the political dimension, the public is growing increasing cynical about the decision making process employed by governments. The precautionary approach opens avenues for public input and scrutiny of sensitive decisions. From an economic perspective, the proper application of the precautionary approach is seen to be an element in ensuring that cautious public policy becomes neither a barrier to innovation nor as a trade restriction.

The Canadian Government has proposed that the precautionary approach be implemented in accordance with 11 guiding principles. The first 6 principles, entitled General principles of application , provide guidance on whether on not a particular policy problem justifies the application of the precautionary approach. The final 5 principles, entitled Principles for precautionary measures , provide implementation advice to policy makers once they have decided to apply the precautionary approach.

The core considerations for the implementation of the precautionary principles are: 1) is there scientific evidence of a credible threat to human health, safety, the environment or resource conservation; 2) will the threat exceed society s risk tolerance threshold; and, 3) who is responsible for generating the scientific data? Once it is decided to use apply the precautionary principle in a given situation, there is a recognition that the perception and quantification of risk changes over time, and that any decisions are subject to review. There are also the requirements that risk mitigation measures are to be applied in a consistent, fair and reasonable manner, and that the overall impact of risk mitigation is to be cost-effective.

2. Risk Assessment and Perception

At its core, the precautionary approach is a risk management tool. In order to interpret how the precautionary approach could be used in the maritime context, it is important to have an understanding of the methods of assessing and perceiving risk.

From a quantitative point of view, risk can be described as the likelihood that an unwanted event will occur and the cost incurred when the event occurs. In this sense, risk can be expressed as the total expected loss taking into consideration the probability of all possible events and the costs associated with each event. Mathematically, risk would be derived using the general equation for calculating an expected value.

$$E(X) = n \cdot \sum_{i}^{n} x_i \cdot p(x_i)$$

where $p(x_i)$ is the probability that the i^{th} scenario will occur°; x_i is the loss that would be incurred if the i^{th} scenario occurs°; $\sum_{i}^{n} x_i \cdot p(x_i)$ is the sum of losses for all scenarios for a given system (it is also the mean loss for a given system); n is the number of independent and identical systems in operation°; and $E(X)$ is the total expected loss for all systems in operation.

To use this method, the analyst would need, for a given system, to 1) list all possible scenarios that could lead to a loss; 2) for each scenario, determine the cost associated with the loss; 3) for each scenario, determine the probability that the scenario will occur; and 4) identify the number of independent and identical systems that are also in operation to which the analysis can also apply.

The method of calculating an expected value is used in a number of circumstances. At the macro-level, it is used as a sensitivity-mapping tool to prioritize a list of loss producing scenarios. The Canadian Office of Critical Infrastructure Protection and Emergency Preparedness (formerly Emergency Preparedness Canada) advocates this approach when building contingency plans[ii]. At a micro-level, the expected loss method is used to quantify the risk of well-defined systems or sub-systems. Again, the method helps to identify particularly sensitive risk elements, and can help to estimate the cost-benefit of implementing certain loss reducing actions.

The expected value method, however, has difficulties in dealing with low probability — high cost scenarios[iii]. By their very nature, low probability scenarios are very difficult to define in advance through analytic reasoning. The chain of events leading to real-life maritime accidents are usually so convoluted that no reasonable person could foresee its occurrence. The old adage that a mariner s life is 99% boredom and 1% excitement underlines the fact that most voyages are uneventful and routine. Indeed, accidents seem to have a random nature, striking where and when least expected. When faced with this situation, the analysis shifts from cause-and-effect to determine the likelihood of an event occurring, and switches to observations of past trends.

From a statistics point of view, the occurrence of shipping casualties is analogous with binomial distributions. In other words, incidents at sea are like with a random sample from a jar containing a large number of balls labeled safe , and a small number which are labeled accident . For each voyage of each vessel, a sample is drawn from the jar. If a safe ball is drawn, nothing happens. If an accident ball is drawn, the ship suffers a casualty (e.g.: grounding, fire, collision, etc.)[*]. Increased marine activity increases the number of samples. Technology and regulatory controls, or lack thereof, can increase or decrease the number of balls labeled accident . As long as the number of voyages is large and the number of safe balls is very much larger than the number of accident balls, the system will <u>appear</u> to be random. Mathematically, binomial distributions with these characteristics are best approximated by a Poisson (random) distribution.

$$p(x) \cong \frac{e^{-\mu} \cdot \mu^{x}}{x!} \text{ and } \mu = n \cdot p$$
$$\text{if } n \to \infty \text{ and } p \to 0$$

So much for theory. In practice, maritime administrations, shipping companies, and maritime underwriters face a daunting task. The number of risk scenarios, as well as the estimated likelihood that a scenario will occur are based on observations of past incidents or near-misses. There are a number of implications of the observation that risk is estimated from historical data. The first is that some low probability — high cost scenarios will be missed because they haven t happened yet. The second is that observational studies do not reveal cause-and-effect relationships, and cannot be used to accurately predict the results of changes to the system. The third is that the perception of risk will lag the actual risk due to the time taken for a statistically significant trend to emerge in the data. The result is that, in the absence of research, the impact of new technology or new policy on risk can only be measured after the fact, that is, through a trial-and-error process.

Is the trial-and-error method a reasonable means of managing risk in the maritime industry? According to the precautionary principles, the answer partially lies in society s chosen level of risk. For society, risk analysis does not involve any statistical methods, but is rooted in perception. For the general public, the primary source of information from which to form a perception of risk in shipping comes from media reporting of casualty reports; information produced by government bodies; and the rare political debate on issues related to shipping. The public perception of the risk of maritime activities is difficult to gauge. The only real methods available are the political processes and the public consultation process - both of which are fraught with misleading signals.

If it is accepted that no system can be made entirely risk free (i.e.: the expected loss will always be greater than 0), it must also be accepted that there is a certain threshold of acceptable risk. The term acceptable must be interpreted with caution. It should not be viewed that the consequences associated with risk are desired, but rather that the principle of diminishing returns indicates that further measures to reduce risk are not cost-effective. The

[*] The Canadian Transportation Safety Board 2001 annual report indicates that for every 1000 trips of commercial vessels in Canada, there are 3.60 shipping accidents.

concept of acceptable risk becomes even more complicated when one considers that society appears to adjust its behavior to be either more or less risky so that the acceptable risk threshold is achieved.

Gerald J.S. Wilde[iv] contends that there is a risk homeostasis or target risk that individuals attempt to achieve. For example, if the individual feels more secure by wearing a seatbelt, then the same individual should drive a bit more recklessly (by increasing speed for instance) until the security of the seatbelt is offset by the risky driving. In this simple example, the individual is striving to achieve a target risk. The shipping industry also seems to follow this pattern of assuming a target risk. The introduction of technology that reduces risk (RADAR for example) induces more risky behavior (higher speeds in poor visibility). One of the key roles of Maritime Administrations is to promulgate and enforce public policy that ensures that the target risk accepted by society is achieved by the maritime industry under its jurisdiction.

An important implication of risk homeostasis is that equilibrium is maintained until there is a change in either risk aversion or the perceived expected loss. While risk aversion is a relatively stable characteristic, expected loss can change relatively quickly. Recalling the equation for expected values, expected loss can increase with increases in the accident rate, the value of loss, the number of loss producing scenarios, or the activity level. A detailed examination of these factors is beyond the scope of this paper, however there are clear signals that the overall expected loss rate is increasing in Canada.

The clearest signal that overall expected loss is increasing comes from the maritime insurance industry. The role of maritime insurance is to protect business interests against loss producing shipping accidents through the provision of coverage in exchange for a premium. The insurance industry can only survive if the premiums collected exceed the value of claims paid, and are thus very sensitive to both the expected (upon which premiums are based) and actual loss rate (upon which claims are paid). In 1999, the global loss in marine insurance was estimated to be $3 Billion (US), and the Central Union of Marine Underwriters in Norway stated that with loss ratios of 160 — 170%, marine underwriters need a premium increase in the order of 100% [v]. The December 2001 issue of The Log (published by the Canadian Board of Marine Underwriters), indicated that there were significant losses in Canada in 2001, and that there was likely to be an increase in premiums as well as an overall reduction in available coverage in order to keep the industry afloat[vi].

It is also fairly clear that the public perception of the "costs" of maritime activities is moving away from the accountant's view of book cost and towards the economists view of opportunity cost. In the environmental field, the perception of costs of damage to the environment have increased over time. The current debate over the impact of ballast water discharge, and the substantial increases in oil spill liabilities in the aftermath of *Exxon Valdes* are evidence of this shift in perception. Through the introduction of the International Safety Management (ISM) Code, liability for a casualty has expanded beyond the Master to include the managers of the shipping company itself. In the Canadian offshore oil and gas sector, safety of offshore workers became a significant point of public interest in the aftermath of the *Ocean Ranger* disaster[vii].

With the increase in the value assigned to a maritime loss, it is important to look at the trends in the accident rate. In order to maintain risk homeostasis, the accident rates should be dropping. Data from reports issued by the Transportation Safety Board of Canada[viii] and the Canadian Coast Guard s Search and Rescue Program[ix] indicates that there has not been any change in the frequency of serious, loss producing, accidents in Canada. Indeed, in portions of the fishing sector, the accident appears to be increasing[x].

For the purpose of the analysis, the authors attempted to identify data sets that are not subject to changes in reporting criteria, and represented a loss. Data from the Canadian Coast Guard Search and Rescue Program and from the Canadian Transportation Safety Board were selected.

From the search and rescue data, the data associated with the number of incidents reaching the distress phase were chosen. The criteria for the declaration of distress are less subjective than the criteria used to declare the alert or uncertainty phases.

Number of Distress Incidents Reported in Canada				
1995	1996	1997	1998	1999
771	665	684	681	697

Within the Transportation Safety Board data, the normalized accident rate for Canadian registered commercial vessels, the numbers of commercial vessels lost, and the fatality rates were used.

Canadian Commercial Vessel Accident Rate (shipping accidents per 1000 trips)									
1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
4.83	4.01	4.11	4.09	4.27	2.92	3.45	3.80	3.24	3.60

Commercial Vessel Loss Rate — Canadian Waters									
1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
5	9	9	7	7	7	8	5	3	7

Fatality Rate — Canadian Waters									
1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
15	10	12	11	13	12	10	15	15	17

Regression tests on the above data sets does not support the hypothesis that there has been any change in the loss producing accident rate in Canada.

The net result is that the maritime transportation system is moving in a direction that will likely require the application of the precautionary principle (i.e.: scientific uncertainty and an increase in the overall expected loss). The next question then becomes one of identifying the key issues that require investigation that have a high likelihood in reducing the accident rate in shipping. From previous studies, it would appear that investigations directed towards human performance would be the fruitful area of research.

3. Human Performance and the Risk of Maritime Incidents

Human error is present in 80% to 90% of all shipping accidents[xi]. Det Norske Veritas has recently concluded that human error still continues to be a serious challenge, accounting for 58% of major [insurance] claims [xii].

In 1996, the European Commission, as part of its 4th framework research program, commissioned a study entitled Maritime Standardised Simulator Training Exercises Register (MASSTER). The objective of the MASSTER study was to investigate the standardization of simulation exercises within Europe as part of the implementation strategy of STCW 95. One of the tasks of the MASSTER program was to investigate human error, and a working paper entitled Improving Human Error Control in Maritime Simulator-based Training (WP 3) was produced[xiii].

The general model for human error in the MASSTER report was described as a five stage process leading to an accident. The first stage consisted of latent errors, or general failure types. The general failure types are the triggers that set the entire human error chain in motion. The latent failures are related to the environment in which the human operates and includes diverse elements such as equipment design, work processes, training, and error trapping methods. The MASSTER report noted that these latent failures are usually the result of decisions made by the upper level in systems, such as decision-makers, legislators, designers, managers, [and] inspectors .

An example of a general failure type in action would be the potential for a communications error caused by an inaccurate or incomplete Maritime Mobile Service Identity (MMSI) database. MMSI numbers are analogous to a telephone number issued to a ship, and are used as a ship identifier in distress messages. An inaccurate or incomplete database has the potential to hamper communications in a crisis, and represents a latent error. Whether or not the latent communications error will ultimately lead to an accident depends on a number of factors, outlined below.

The second stage of human error was identified as psychological precursors that aggravate the latent error. The main psycological precursors were identified as slips, lapses, and mistakes. Slips were defined as an error in the execution of an otherwise perfect plan ; lapses are losses of memory; and, mistakes are the perfect execution of a wrong plan . There are various sub-categories of psychological precursors, and different precursors occur under different conditions.

The third stage of human error is the commission of a substandard act. It is important to note that the commission of a substandard act is the first observable event in the human error chain. Of itself, a substandard act (e.g.: incorrect helm order) does not cause an accident, but causes an operational disturbance (e.g.: ship turning in wrong direction) that can ultimately lead to an accident. Substandard acts caused by slips can be detected and corrected relatively easily because the deviation in performance is different from the expected outcome. Mistakes, on the other hand, are difficult to detect except in hindsight because the substandard act cannot be recognized as a deviation until the scenario has progressed to its final conclusion.

The fourth stage consists of the barriers between an operational disturbance and an accident. In some cases, the barrier is situational in nature, that is, the conditions are not right for an accident to occur. In the example above, a ship turning the wrong direction has different implications in the open sea as opposed to confined waters. In other cases, the barrier consists of error trapping methods designed to detect and prevent accidents. For example, procedures that promote bridge team members to monitor and challenge each other would detect the incorrect turn before it progressed to an accident.

Operational disturbances that breach the barrier defence results in the fifth, and final stage, which is the occurrence on an accident. As can be appreciated from the above description of the process of human error, the accident represents the final stage after of a long sequence of events that has as its roots factors that pre-existed a particular situation got the ball rolling. Within the chain, however, there are four dominating factors that justify closer scrutiny.

The first factor is the limits of human cognitive capacity. The MASSTER report indicated that the overall category of cognitive problems accounted for 70% of the errors, and was present in 93% of the accidents . Within the MASSTER report, cognitive problems were defined as 1) false hypothesis 2) habits 3) personality and training . While improvements to training are undeniably a good strategy for reducing cognitive problems, training cannot be the only strategy. For instance, the MASSTER report indicates that there is a high correlation between information processing and high environmental stress. This finding confirms the Yerkes-Dodson law that predicts a serious degradation of human performance beyond a certain optimal arousal[xiv]. Overloading of the cognitive faculties of an operator is not a problem that can be solved exclusively through training, but needs investigation into ergonomics and work processes as well in order to engineer the overloading conditions out of the system.

The second factor is the influence of organizations on human error. A 1995 paper entitled *Human and Organization Factors (HOF) in Design, Construction, and Operation of Offshore Platforms* described the impacts of human error on the quality assurance and quality control processes in the offshore industry[xv]. The paper indicates that the single most pervasive HOF influence on quality in marine systems is organizational. Organizations in one way or another are largely responsible for creating the situations that either lead to or prevent major accidents . Human error induced by organizations has far reaching implications at both the corporate and legislative levels. Corporate culture is as important as policies and procedures for the introduction of latent errors due to organizational factors.

The third factor is the error trapping abilities of human. It has been observed that humans are much better at error trapping than error avoidance if they are given adequate opportunity. In other words, it is easier to recognize an error than anticipate one. In this sense, while organizational risks need to be engineered out of the system to the extent possible, the individuals within the organizations need to be prepared for crisis management. In terms of the MASSTER report, preparation in crisis management is equivalent to bolstering the defenses that prevent operational disturbances from becoming accidents. Such defence mechanisms were outlined as improved equipment and information design, development of emergency strategies, and training in crisis situations (especially simulator training).

A final point to consider is the impact of change on the creation of latent errors. Bea and Roberts observed that the rapid pace at which significant industrial and technical developments have taken place, there is a tendency to make design guidelines, construction specifications, and operating manuals more and more complex . The increasing complexity of modern systems is promoting the growth of latent human factor errors. While Bea and Roberts were specifically referring to improper documentation and procedures, the observation can be applied to the other elements of latent errors including regulatory regimes that lag technological innovation.

Within Canada, the potential for the proliferation of latent errors is significant. The Canadian maritime industry is in the midst of large and fundamental changes. Firstly, the entire regulatory framework surrounding shipping is in a state of flux. The Canada Shipping Act has been completely rewritten, and its associated Regulations are currently under-going extensive revision and consolidation[xvi]. This initiative is being undertaken by a Federal civil service that has been decimated by staff reductions. Secondly, the Federal Government is attempting to stimulate productivity through innovation[xvii]. With an expressed goal of doubling investment in R&D over the next 10 years, the already fast pace of introduction of technology into the workplace will further accelerate. Thirdly, the maritime industry is expanding into new areas and activities. The offshore oil and gas industry is accelerating on the Canadian East Coast and is expected to open on the West Coast and in the Arctic. Shipping activities are moving towards remote areas such as the Labrador coast where bulk carriers will be shipping nickel from Voisey s Bay and cruise vessels will be exploring remote fjords. Fourthly, maritime activities are being conducted in harsh environments, especially environments associated with ice. Iceberg towing, for example, is a necessity to permit drilling operations on the Grand Banks.

With the magnitude of the changes happening in the Canadian maritime industry, and without a clear understanding of the cause-and-effect relationships in maritime accidents, there is no assurance that there will be any reduction in the maritime accident rate in Canada. In fact, the opposite may be true. Rapid innovation without a clear understanding on the impacts on human performance may very well stimulate the creation of latent errors that lead to accidents, and ultimately increase the overall expected loss attributed to maritime operations.

4. Simulation and Modeling as a Risk Management Tool

Human error is not a new concept in maritime transportation. Until the advent of advanced simulation technology, there were few tools available to identify human factor problems other than operational analysis by experts. In the past, testing of new systems was done by deploying a few systems in the field, and observing the impacts on performance through sea trials.

Sea trials, while satisfactory for proving engineering concepts, are a poor method of investigating human performance issues. Firstly, crisis situations cannot be replicated safely in live systems. Secondly, only a limited number of people can participate in a sea trial making the observed results difficult to extrapolate to the entire marine community. Thirdly, it is difficult to control for variables in sea trials making it very difficult for investigators to identify cause-and-effect relationships. As a result of these three shortcomings, new technology and work processes are often introduced with little knowledge of its impact on human performance. The impact of Digital Selective Calling upon communications at sea is an example[xviii].

In the early 1990 s, military planners in the Unites States Department of Defense were facing a similar situation where there was a requirement to rapidly innovate, maintain operational performance, and remain cost effective. The traditional innovation method used by the military was judged to be too expensive and ineffective. After some analysis, the military turned to modeling and simulation as a means to provide readily available, operationally valid environments [xix].

Before commencing a discussion on how simulation and modeling is used as a risk management tool, it is important to present the US DoD definitions of the terms modeling and simulation . Modeling is the application of a standard, rigorous, structured methodology to create and validate a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (DoD Publication 8320.1-M, (reference (j)). Simulation is a method for implementing a model over time (DoD Directive 5000.59 and DoD Publication 5000.59-P, (references (f) and (g)).

From the US DoD perspective, modeling and simulation are expected to have benefits in four key areas, namely: readiness, modernization, force structure, and sustainability. The benefits in readiness include training and assessment; development of doctrine and tactics; and mission rehearsal. For modernization, the benefits include improved efficiency in the acquisition process and improvements in the quality of systems. For force structure, modeling and simulation is expected to assist in the optimal deployment and tasking of resources, while under sustainability, life cycle cost management is expected to improve. Within the United States, the Defense Modeling and Simulation Office (DMSO) oversees the US military s simulation and modeling efforts.

In order to achieve the expected benefits, the US DoD has defined an implementation strategy consisting of 6 theme areas. Of particular interest to the civilian community is the substantial investment being made to improve simulation technology, and the desire to engage the broader community in simulation and modeling through joint technology development and technology transfer. The work being done to improve simulation technology has resulted in the growth of open systems that are modular and recyclable. The efforts to define High Level Architecture (HLA) and the development of readily available Run Time Infrastructure (RTI) are examples of development in simulation technology. The authors believe that such developments will ultimately reduce the costs associated with simulation projects in the civilian sector making simulation and modeling more accessible for commercial applications.

In Canada, the Department of National Defence has initiated its own simulation program called Simulation and Modeling for Acquisition, Research and Training (SMART)[xx]. Recognizing the importance of human performance on system effectiveness, the SMART program is being implemented through the Canadian Military s human factors researchers at Defence R&D Canada — Toronto (DRDC Toronto and formerly the Defence and Civil Institute of Environmental Medicine). Within the maritime sector, DRDC Toronto has conducted a variety of projects including distributed simulations of warship formation maneuvering; helicopter deck landing simulation; and human performance issues related to the use of electronic charts. The electronic chart research, in particular, has a direct relation to regulatory initiatives within Canada for the civilian sector, and has involved the use of simulation facilities at the Centre for Marine Simulation.

The lesson to be learned from the military is that simulation has a much wider application than training in the reduction of human error. Simulation is aggressively being pursued as a tool to address latent human factor issues that are present in the general failure types outlined in the MASSTER report. The civilian (maritime) community has not picked up on simulation to the same extent as the military. Although simulation is now a mandatory component in mariner training (but only for the operation of radar), the use of simulation to address the human factors in marine operations is sporadic and haphazard. As far as human performance is concerned, the maritime industry continues to rely upon trial-and-error when implementing new technology or work processes.

5. Using Simulation and Modeling in Public Policy Research

At its core, public policy research is concerned with goodness and utility. That is, what are the right things to do, and what are the best ways of doing them? The answer to the first question is a philosophical question, while the second is economic. While there are few who would argue that safety at sea and protection of maritime environment are not good objectives of society, there is certainly debate on the extent to which these objectives can be achieved. One of the goals of the public consultation process in Canada is achieve a balance between the costs of protective measures and the costs of expected loss.

The public consultation process relies upon evidence presented either through scientific studies, observation of trends, or professional judgement in order to determine if an appropriate balance is being struck between protection and loss. The authors participate in the primary maritime consultative forum in Canada, the Canadian Marine Advisory Council (CMAC), and have observed that the evidence to support or refute maritime related policy initiatives usually has very little scientific backing.

Application of the precautionary approach in the maritime sector implies that an increased level of scientific evidence will be required to support policy initiatives. The scientific evidence demanded by the precautionary approach does not demand conclusive proof, but rather sufficiently sound scientific information . Expert opinion and data from observational studies can continued to be accepted, but the need for experimental evidence will increase. With human performance as a key determinant of safety and environmental protection, simulation and modeling will become a critical tool in future public policy research.

An example of how simulation and modeling could produce experimental evidence to support the implementation of public policy would be mission rehearsal. The mission rehearsal process could be used to develop and validate operational and contingency plans; determine the need for, and effectiveness of, publicly funded infrastructure; and, evaluate the effectiveness of new technology. To use mission rehearsal, the operating conditions would need to be modeled, and then professionals would participate in a series of simulations to determine. Simulation and modeling, in this sense, represents a tool to generate artificial experience that would significantly improve professional judgement in the consultation process, especially with respect to human performance.

In general there are two objectives for simulation and modeling in the maritime sector. The first is to address the existing problems related to human performance and the second is to ensure that additional latent human errors are not introduced into the marine transportation system. In order to achieve these two objectives, the existing simulation capability in Canada must be mobilized to undertake human performance research; advanced simulation and modeling capabilities must be established; and funding to cover the costs of simulation and modeling must be identified.

To date the Federal and Provincial Governments have invested well over $30M to establish a maritime simulation capability in Canada[xxi]. At the present time, the Canadian capability is primarily used for training, and its capabilities to conduct human performance research has been largely untapped. Aggressive utilization of existing simulation capabilities will help to address operational issues such as process/procedure validation, crisis management methods, and new equipment prototyping.

Even though the existing simulation infrastructure is useful to investigate general human performance issues, they are somewhat limited to deal with specialized issues, such as performance in harsh environments. An initiative to create advanced simulation and modeling capabilities (both in terms of physical infrastructure and expertise) for researchers to investigate the broad spectrum of human performance issues related to marine transportation is essential. Investment into improved numerical models, improved simulation technology, and improved evaluation methods using simulators will provide the necessary tools to address the introduction of latent human error through the process of innovation.

Transport Canada supports research of maritime issues through its Montreal based Transportation Development Centre (TDC). According to TDC s 2001 annual report, Transport Canada s contribution to maritime research was approximately $1 million (CAD), a fraction of which was spent on human factor s studies[xxii]. This level of investment by Transport Canada seems woefully inadequate to support its sweeping regulatory changes in the marine sector and must be increased.

The Federal government, however is not the only stakeholder with an interest in reducing human error in the maritime sector. The private sector also has a role to play through sponsoring and participating in human performance research. A collaborative funding and priority setting effort on the parts of the public and private sector will permit the academic and scientific communities to produce the necessary scientific evidence required by the precautionary approach.

Industrial clusters have demonstrated their worth in focussing the efforts of the academic, scientific, industrial, government, and capital communities to accrue maximum benefits. Within Canada, an Ocean Technology Cluster has been created[xxiii], and should include simulation and modeling as part of its core capabilities. The authors believe that innovation can only result in productivity improvements if human performance elements are factored into the creation of new technology or work processes. When considering innovation in the maritime sector, a portion of any increased R&D investment must be directed towards human performance, especially the mitigation of latent errors induced by rapid change.

6. Conclusion

With the rewriting of the Canada Shipping Act and its associated Regulations, the regulatory structure surrounding marine transportation is undergoing a fundamental change for the current system that has its roots in the mid-1800 s. At the same time, new technology is proliferating all aspects of marine transportation with the potential to revolutionize and optimize work processes.

Without addressing the chronic issue of human error, however, the maritime transportation system in Canada, already feeling the effects of spiraling costs associated with accidents, will have difficulty in absorbing the sweeping changes currently underway. Without mitigating the impacts of human error, innovation in the maritime sector may introduce more cost than benefit and not be sustainable in the long run.

Increases in the expected cost of loss activates the public interest, and leads to the implementation of the precautionary approach in the maritime sector. Simulation and modeling provides a capability to address human performance issues, and to contribute to the increased requirement for scientific information demanded by the precautionary approach. Utilizing existing simulators, as well as investment in specialized simulation and modeling capabilities, should lead not only to reductions in the accident rate, but also to improved productivity.

Memorial University of Newfoundland already possesses many of the elements required to host a comprehensive simulation and modeling program directed at the Canadian maritime sector. Through the Marine Institute, Memorial University is in the process of mobilizing its capabilities, as well as those of the Canadian Ocean technology community, to establish the necessary simulation and modeling capabilities to support public policy research in Canada.

---

[i] Government of Canada. *A Canadian Perspective on the Precautionary Approach/Principle*. Ottawa: http://www.pco-bcp.gc.ca/raoics-srdc/docs/Precaution/Discussion/discussion_e.pdf, 2001. Unless otherwise noted, references to the precautionary approach are derived from this document.

[ii] Personal communication with Regional Director General, OCIPEP Newfoundland.

[iii] Hammer, Willie. *Occupational Safety Management and Engineering*. Englewood Cliffs, NJ: Prentice-Hall Inc., 1981.

[iv] Gerald J.S. Wilde. *Target Risk*. http://pavlov.psyc.queensu.ca/target/#contents.

[v] The Central Union of Marine Underwriters (CEFOR). *Premiums on the rise —Shipowners to expect substantial increases*. Oslo, Norway: http://www.cefor.no/news/pdf/CEFOR%20Press%20Brief%20290301.PDF, CEFOR Press Brief, 29 March 2001.

[vi] The Canadian Board of Marine Underwriters. *The Log*. Mississauga, Ontario: http://www.cbmu.com/CBMULog_Dec01.pdf, 2001.

[vii] Patterson, Anthony. *Evolution of Training for the Maritime Oil and Gas Sector on the Canadian East Coast*. St. John s: presented at Canada-Brazil Health, Safety, and Environment Seminar and Workshop, Rio de Janeiro, 2002.

[viii] *TSB Statistical Summary Marine occurrences 2001*. Ottawa: Transportation Safety Board, 2002.

[ix] *Annual Report 1999 — Maritime SAR Incidents*. Ottawa: Canadian Coast Guard, 2001.

[x] Wiseman, Merv and Hedley Burge. *Fishing Vessel Safety Review (less than 65 feet)*. St. John s: Canadian Coast Guard — Newfoundland Region, 2000.

[xi] Derived from the MASSTER Report and Bea and Roberts (see below for full reference).

[xii] *Marine insurance highlights — The Changing Pattern of Risk*. Norway: http://www.dnv.com/dnvframework/forum/articles/forum_2000_01_18.htm, Det Norske Veritas Forum, 2000.

xiii H.J.A. Zieverink et al. *MASSTER - Improving Human Error Control in Maritime Simulator-based training*. Wageningen, The Netherlands: Maritime Simulation Centre The Netherlands, 1997. Unless otherwise noted, references to the MASSTER report are derived from this document.

[xiv] Huey, Beverly Messick and Christopher D. Wickens, editors. *Workload transition — Implications for Individual and Team Performance*. Washington D.C.: National Academy Press, 1993.

[xv] Bea, R.G. and K.H. Roberts. *Human and Organization Factors (HOF) in design, Construction, and Operation of Offshore Platforms (OTC 7738)*. 27th Annual OTC in Houston, Texas, 1-4 May 1995. Unless otherwise noted references to Bea and Roberts are derived from this document.

[xvi] Patterson, Anthony. Personal notes from the May 2002 Canadian Marine Advisory Council meeting: Ottawa, 2002.

[xvii] Government of Canada. *Achieving Excellence: Investing in People, Knowledge and Opportunity*. Ottawa: http://www.innovationstrategy.gc.ca/cmb/innovation.nsf/MenuE/InnovationStrategy, 2002.

[xviii] Patterson, Anthony and Philip S. McCarter. *Digital Selective Calling: The Weak Link of the GMDSS*. Journal of Navigation, Volume 52, Issue 1, 1999.

[xix] Department of Defense (US). *Modeling and Simulation (M&S) Master Plan*. Washington: https://www.dmso.mil/public/library/policy/guidance/500059p.pdf, 1995. Unless otherwise noted, references in this paper to US DoD simulation and modeling initiatives are derived from this document.

[xx] See http://www.Toronto.DRDC-RDDC.gc.ca/DRDC-Toronto/research/simmod_e.html for details.

[xxi] Based upon the authors estimation of the value of simulators installed at Canadian maritime training institutions and the Canadian Navy.

[xxii] Transport Canada. *Transportation Development Centre Annual Review 2000 — 200: Celebrating 30 Years*. Montreal: http://www.tc.gc.ca/tdc/publication/pdf/anrev/2001.pdf, 2001.

[xxiii] National Research Council Canada. *Ocean Technology Cluster Planned for St. John s*. St. John s: http://www.nrc.ca/imd/imd_spring_2001.pdf, IMD Research News, 2001.