Simulation and Modeling in Innovation[a]

Anthony Patterson M.M.
Director
Centre for Marine Simulation
Fisheries and Marine Institute of Memorial University of Newfoundland

Introduction

Within Canada, the Federal government has initiated a comprehensive program to improve productivity through innovation. By 2010, research and development expenditures made by the Federal government are projected to double, and Canada is expected to become one of the top five research performers[1]. As part of its innovation agenda, the Federal government has begun a number of initiatives to identify areas of investment, and has begun the process of increasing R&D investment through mechanisms such as the Atlantic Innovation Fund[2].

Within the Oceans Sector, which includes maritime transportation, the initiatives undertaken by the Federal government include the creation of an Ocean Technology Cluster in St. John's[3]; the commencement of an ocean technology road mapping exercise; and the sponsorship of a consultation process within the academic, scientific and business communities to identify innovation priorities. Some Provincial jurisdictions within Canada have also launched programs in parallel with the Federal initiatives[4].

Technology development, however, is only one dimension of the innovation process. Without efforts to integrate technology into work processes, taking into account issues related to human performance, real productivity improvements are difficult to achieve. The introduction of new technology in the workplace without a clear understanding of its interaction with human performance can stimulate the creation of factors ultimately leading to human error. Human error, in turn, leads to costly accidents, and thereby offsets any incremental improvements realized by the new technology in the first place.

Simulation and modeling are valuable tools to identify and quantify the impacts of new technology on human performance. The simulation and modeling tools, if applied early in the innovation process, can help to offset human performance issues through improved design, procedures, legislation, and training. The purpose of this paper is to explore some of the innovation issues currently facing the maritime industry in Canada and to outline how simulation and modeling can ensure that the intended productivity improvements are realized.

Innovation

For the purposes of this paper, an economic definition of innovation will be used[5], namely: "innovation is the introduction of an invention into methods of production." Invention is "the discovery of something new, such as a production technique or product". From the above definitions, investment in research does not necessarily lead to productivity improvements. Research without innovation results in stranded technology, that does little, if anything, to improve the methods of production.

In principle, the process of innovation contributes to the improvement in productivity (the ratio of value of output to cost of input)[6]. Innovation increases production potential that can result in either more goods/services produced for the same cost or the same number of goods/services produced at a reduced cost. Demand for the good or service becomes the determinant of ultimate impact of the innovation. For example, a port may introduce an innovative vessel traffic management system that reduces both the cycle time and cost for individual ships to use the harbour. If there is high demand to ship commodities from the harbour, then the revenues from increased traffic would pay for the system.

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If traffic demand remains unchanged, then the reduced overhead costs to administer the port would pay for the system.

The key concept with innovation is that the method of production is somehow altered. In some cases innovation results in the substitution of labour with capital (or vice versa), and in other cases, innovation results in improved efficiency of existing labour and/or capital. In the shipping world, there is a trend towards the introduction of automation as a means to offset labour costs. The implementation of GMDSS is an example of this trend. Prior to GMDSS, long-range radio communications were conducted by specialized radio operators both onboard ships and in shore stations. With GMDSS, ship owners were permitted to remove radio officers and concentrate the communications function in deck officers, and Administrations were able to reduce the number of coastal radio stations. Other examples of the automation trend would include unmanned engine-rooms, dynamic positioning, and automatic information systems.

Innovation is usually initiated in response to external factors that stimulate the need for improved efficiency. Most innovation projects require a sustained investment in order to bring the new product or process into the workplace, and represent an element of financial risk. Private sector companies need to be convinced that an innovation will result in an adequate return before the investment is made. The public sector follows a similar process, but also needs to factor in the overall benefits to society as a result of the innovation, some of which are not measured in financial terms.

The importance of sustaining the motivation to see an innovation project through to conclusion is also an important factor to consider. In his paper *A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation*, Nelson Repenning notes "the history of management practice is filled with innovations that failed to live up to the promise suggested by early success…there is often compelling evidence suggesting that, were the innovation on question appropriately adopted and implemented, the organization would benefit significantly"[7]. Repenning illustrates how maintaining commitment to a project includes factors such as re-enforcement (success breeds success), diffusion (buy-in from the workforce), and normative pressure (management support and expectations).

Innovation in Canada's Shipping Sector

The Canadian maritime community is in the midst of substantial changes. A few examples will serve to highlight the magnitude of the changes. The Canada Shipping Act, with its roots in the 1800's, has been rewritten, and its associated Regulations are currently under-going extensive revision and consolidation. The offshore oil and gas industry is accelerating on the Canadian East Coast and is expected to open on the West Coast and the Arctic. Fishing activities on the East Coast of Canada has been substantially altered with the collapse of the cod stocks. Iceberg towing has become a routine operation on the Grand Banks in order to protect the offshore oil and gas assets, and cruise vessels are operating in the Arctic.

At the present time, the forces of innovation within the Canadian maritime community are the need to reduce the costs associated with public infrastructure; the expansion of maritime activities into remote and harsh environments; and, the need to improve transportation security. The author projects that the need to reduce costs associated with maritime accidents, especially those caused by human error, will become the next stimulant of innovation within the Canadian maritime community.

The costs associated with maritime accidents are increasing. In 1999, the global marine insurance industry lost $3 Billion (US)[8]. In the year 2001, the US insurance industry was bracing for the largest loss since 1949 even before the terror attacks on September 11[9]. Premiums are expected to rise, and scope coverage is expected to drop in order to keep the marine insurance industry afloat[10].

With the value of claims rising, the accident rate must be reduced. Human error continues to be a dominant factor in maritime accidents, being present in 80%-90% of all shipping accidents and responsible for 58% of major insurance claims[11]. The insurance industry is likely to demand increased measures by the shipping industry to reduce human factor errors through a " focus on safety management and management control, loss prevention measures, operational performance and loss records"[12].

The process of human error includes latent factors that, in combination with "psychological precursors", lead to incorrect actions and ultimately to accidents[13]. Latent errors come from a variety of sources, including the "rapid pace at which significant industrial and technological developments have taken place"[14].

Human error is not a new concept in maritime transportation. Until the advent of advanced simulation technology, however, 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.

Simulation and Modeling

Sea trials 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[15].

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 and maintain operational performance in a cost effective manner[16]. The traditional innovation method used by the military was judged to be too expensive and ineffective. After some analysis, the US DoD turned to modeling and simulation as a means to "provide readily available, operationally valid environments".

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 Canada, the Department of National Defence has initiated its own simulation program called Simulation and Modeling for Acquisition, Research and Training (SMART)[17]. 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.

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 author believes 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.

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.

The following examples illustrate the potential benefits of inserting simulation and modeling into the maritime innovation cycle.

An example of how simulation and modeling could reduce the latent error in maritime systems would be mission rehearsal. The mission rehearsal process could be used to evaluate the impact of new technology or doctrine on human performance, and result in improved design; effective operational and contingency plans; efficient publicly funded infrastructure; and, improved regulatory controls. To use mission rehearsal, the operating conditions would need to be modeled, and then professionals would participate in a series of simulations. 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.

Mitigating the impact of psychological precursors to human error involves using modeling and simulation to observe and quantify human performance of mariners, particularly their cognitive performance in operational contexts. For example, the Yerkes-Dodson law[18] predicts poor performance for workers that are over stimulated. It would be important, for example, to conduct baseline studies to determine the stress absorbing capacity of mariners under a variety of operational conditions. The baseline studies would serve to highlight operations and situations where over-stimulation is likely to occur. Another important area of research would be to look at the fatigue induced by highly integrated displays. Most automated display systems have the potential to be integrated with other displays. The question becomes one of the degree to which these displays should be integrated in order to maintain optimal human performance.

Error detection and correction, as well as crisis management, are the last defences in the human error chain. At the present time, maritime simulators are used to train mariners how to detect and correct errors, and to a limited extent on how to manage a crisis. The scope and amount of simulator based training in crisis management needs to increase. Areas such as initial actions to an oil spill and a distress incident need to be incorporated into simulation training programs. Simulation based training in the corporate emergency procedures also needs to be conducted to ensure that mariners are not reaching for the emergency manuals to find out what to do once an incident happens. An improved understanding of how crisis management is conducted in the maritime environment is also required to the development of effective decision support systems.

Simulation and Modeling Capabilities Needed for Innovation

The use of simulation and modeling in the innovation cycle demands a higher degree of flexibility in simulation technology than required for the training function. Simulators need to be able to accept input from a variety of model data, and need to be able to interact with other simulators in unusual and unique situations. Open systems with modular and recyclable components are required in order to mobilize the broader academic, scientific, engineering and corporate communities to integrate simulation and modeling into the innovation process.

A recent requirement to introduce simulation into an offshore oil and gas emergency command and control (C^3) training exercise illustrates the benefits of modular simulation. For the purposes of the C^3 exercise, an input from the process control system is required for the participants. The Faculty of Engineering at our parent university, Memorial University of Newfoundland (MUN), uses a process control simulator for research and training purposes. Through an internet connection, we propose to utilize the Engineering simulator to present a process control display to the participants of the training exercise.

The above example illustrates another important concept. Simulation and modeling components need not be concentrated within a single organizational unit to be successful. Open system that permit various facilities to collaborate on a project specific basis can be equally, if not more, effective. With the example of the process control simulator, as the Faculty of Engineering adds capabilities to their simulator through research activities, our C^3 exercises utilizing the simulator benefit as well.

Such an organizational concept is not without problems, and requires careful planning and management to be successful. MUN, with funding from the Atlantic Innovation Fund, is in the process of defining its system architecture requirements to permit a broad scope of collaboration amongst its simulation and modeling units. The Centre for Marine Simulation is in the process of defining the organizational structure required to mobilize the greater MUN simulation and modeling community to deal with maritime issues.

Conclusion

Without addressing the chronic issue of human error, 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.

In order to reduce the number of accidents caused by human error, effort will have to focus on reducing latent error, mitigating the impact of psychological precursors, and improving the crisis management capability within the maritime community. Such an effort will not only reduce the accident rate, but will help to stimulate the innovation process by making new initiatives more likely to succeed.

Simulation and modeling represents an important capability to ensure that innovation delivers on its promise of improved productivity, and overall wealth generation for Canadians. To achieve the goal of improved productivity, a concentrated effort is required to incorporate maritime simulation and modeling into the innovation cycle.

Within Canada, the Ocean Technology Cluster in St. John's is the appropriate vehicle to develop the advanced simulation and modeling capabilities for the maritime sector. The Ocean Technology Cluster can bring together the various communities to concentrate their efforts in the technical, behavioral and operational dimensions of maritime simulation and modeling.

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

[2] See http://www.acoa.ca/e/financial/aif/index.shtml for details.

[3] National Research Council Canada. *Minister Announces $20 Million for Ocean Technology Cluster.* St. John's: http://www.nrc.ca/imd/imd_fall2001_e.pdf , IMD Research News, 2001.

[4] A *Newfoundland Marine Policy Paper* is in preparation that will address technology and innovation issues.

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[5] Definitions are derived from Lipsey, Richard G. et al. *Microeconomics – Eighth Canadian Edition.* New York: Harper Collins College Publishers, 1994.

[6] This is total-factor productivity and is more of a theoretical concept than a performance measure. Labour productivity (GDP/worker) is a more commonly used measure, but its sensitivity to labour market conditions can hide improvements caused by innovation.

[7] Repenning, Nelson P. *A Simulation-Based Approach to Understanding the Dynamics of Innovation Implementation.* Cambridge, MA: http://web.mit.edu/nelsonr/www/implementation.html, 1999.

[8] 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.

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

[10] Ibid.

[11] *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.

[12] CEFOR Press Brief, 29 March 2001.

[13] *13* 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.

[14] 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.

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

[16] 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.

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

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