Risk Assessment and Management in the 21st-Century Marine Transportation System

MARTHA GRABOWSKI

Fundamental changes are under way that will shape the 21st-century marine transportation system. These changes will have dramatic impacts on the ways in which shippers, ports and waterways managers, regulators, brokers, financiers and insurers, ship's pilots and officers, and scientists work in and around the marine transportation system. In an era of increasing attention to risk-based work practices and decision making, these changes in marine transportation will necessitate changes in risk assessment and risk management processes.

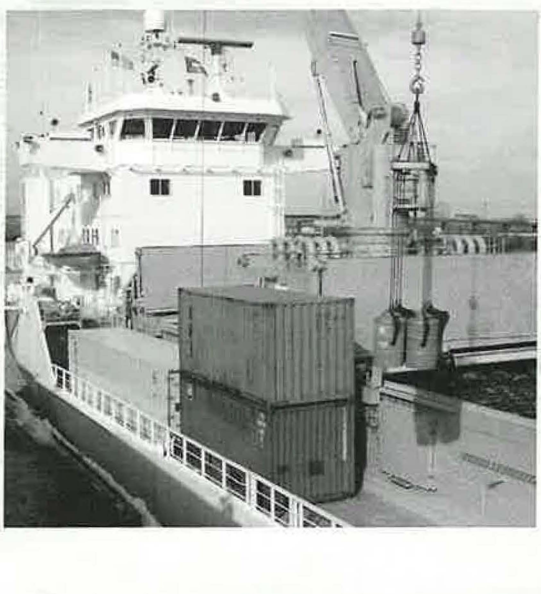
Risk in Marine Transportation

Large-scale systems incur risks through a number of factors. First, the activities performed in the system may be inherently risky (e.g., mining, manufacturing, airline transportation). Second, the technology may be inherently risky or exacerbate risks in the system (e.g., heavy equipment, locomotives, and cables). Yet a third factor is that the individuals and organizations executing tasks, using technology, or coordinating the two can propagate human and organizational errors. In addition, organizational structures may unintentionally encourage risky practices (e.g., lack of formal safety reporting systems or safety departments, or organizational standards that cannot be met without some amount of risk taking). Finally, the organizational culture may support risk taking or fail to sufficiently encourage risk aversion (*1, 2*).

All of the above factors are present in marine transportation. Tasks in the system—navigation, vessel loading, cargo transfer, arrivals and departures—are distributed across a large geographic area, are time critical, and contain elements of embedded risk (vessel navigation in congested waters, in reduced visibility, perhaps carrying passengers or hazardous cargo on time-critical schedules). The technology used in the system (e.g., vessels, equipment, lines) is also inherently risky. Human and organizational error is present in the system, and organizational structures that result in limited physical oversight and contact can make risk mitigation difficult. Finally, the system's organizational culture can send confusing or contradictory messages about risk tolerance (e.g., safety bulletins that celebrate the number of accident-free days while crew schedules and rotations require operators to work long hours).

Characterizing risk in marine transportation, however, presents some challenges. First, because the system is distributed,[1] risk can migrate, making risk identification and mitigation difficult. Second, because marine transportation is a large-scale system with complex interactions among its components,

[1] A distributed system is one in which the system elements are dispersed geographically and have limited physical contact with one another.



Use of heavy equipment, locomotives, and cables contributes to safety risks inherent in marine transportation system.

The author is Professor, Business Department, LeMoyne College, Syracuse, New York, and Research Associate Professor, Department of Decision Sciences and Engineering Systems, Rensselaer Polytechnic Institute, Troy, New York.

U.S. Coast Guard requires passenger ferry operators to either equip vessels with adequate survival craft or provide safety assessment, comprehensive shipboard safety management system, and shipboard contingency plans.

incidents and accidents may have long incubation periods, making risk analysis and identification of leading error chains difficult.[2] Third, because the system comprises members with their own individual goals, policies, and cultures—ashore, aboard ship, in the shipyard—developing a shared culture of reliability can be difficult. These attributes make risk characterization in marine transportation challenging, and also provide important clues about effective risk mitigation approaches.

Risk-Related Changes

Changes currently taking place in marine transportation make risk assessment and management particularly challenging. Three areas of change are salient: changes in the marine transportation regulatory environment, pressures to develop a seamless intermodal transportation system, and the introduction of new technology.

Regulatory Environment

A number of developments signal new international interest in risk-based safety requirements for marine transportation. Examples include the requirement by the International Maritime Organization (IMO) to use risk assessment in decision making, IMO's implementation of Standards for Training and Certification for Watchkeepers, IMO's development of formal safety assessment and high-speed vessel codes, and requirements to comply with the International Safety Management code.

In the United States, the Coast Guard has placed increased emphasis on the importance of risk management in evaluating and prioritizing decision making, and has included risk-based evaluation criteria in recent regulatory efforts. For example, the recent implementation of 46 Code of Federal Regulations (CFR) 199 (Subchapter W) requires ferry operators either to equip all ferries with adequate survival craft or to provide a safety assessment, a comprehensive shipboard safety management system, and shipboard contingency plans approved by the Coast Guard. This represents a significant change in regulatory requirements for passenger ferries, and the new requirements have a significant risk-based management component.

States, provinces, local jurisdictions, and municipalities all over the world, particularly in the United States, have participated in these regulatory changes, often increasing regulatory compliance requirements. The result has been not only more regulatory activity at all levels, but also a mix of regulatory requirements, sometimes in the same jurisdiction. The ensuing patchwork of regulations, some risk-based and some not, can serve as a confusing and frustrating backdrop for the next century's marine transportation operations and commerce.

Pressures To Develop an Intermodal System

Bigger vessels are carrying larger cargo loads and are plying the world's waterways more quickly in an effort to support short turnaround times, tighter delivery schedules, and fluid interfaces with other transportation modes. At the same time, and often on the same waterways, large numbers of passengers are traveling on faster vessels and are sharing the waterways with other commercial and recreational users. The result is greater congestion and shorter time frames within which to react to situations, as well as new expectations and pressures for a seamless multimodal transportation system. Transportation modes are now evaluated on the basis of such

[2] A leading error chain is a sequence of events that precedes an accident or incident and, if recognized, provides warning signs. The errors involved are typically human and organizational—failures to perform tasks, to recognize and act upon critical data, or to respond to small warnings or malfunctions.

parameters as delivery performance, process improvements, cost recovery, benchmarking comparisons, customer and employee satisfaction, economic value added, and conformance to plans (3). The pressures for participation in a seamless intermodal transportation system and the changes in measurement that accompany those pressures impact the levels of risk in the system and the ways risk is measured and managed.

New Technology

New technologies being introduced into the marine transportation system include advanced sensors; navigation, communications, and control system technology; next-generation propulsion and cargo control equipment; high-performance computing, communications, and information infrastructures; maintenance and monitoring technologies; and radical redesigns and upgrades of shore-based facilities. These technologies will be incorporated piecemeal into aging fleets. The result will be a mix of new and old vessels, technologies, and operational dynamics; varying degrees of automation; and frequently a limited understanding of the negative conditions such technology mixes might introduce into the system.

The unsystematic mixing of old and new technologies and a lack of planning for change have produced unintended consequences in other large-scale systems, including aerospace and communications systems, medicine, manufacturing, nuclear power, and telecommunications (4–8). Pressures to introduce new technology into marine transportation must be balanced with requirements to manage and measure levels of risk in the system overall, and must be accompanied by discourse, planning, and ongoing assessment.

Measuring Risk

Risk may be defined as the probability of an unwanted event times the impact of that event. In marine transportation, the risk event may be an *accident* (a collision, fire, explosion, foundering, grounding, or allision[3]), an *incident* (e.g., propulsion, steering, or navigational equipment failure), or an *unusual incident* (e.g., deviation from navigation rules, failure to comply with a requirement). The impacts may include deaths, injuries, environmental damage, and economic losses that occur as an immediate or delayed consequence of the event. To reduce risk, it is necessary to understand risk events and the situations that could lead to those events or exacerbate their consequences.

Risk events may be the result of *basic or root causes*, such as inadequate knowledge, skills, or abilities or an organization's lack of a safety management system. Risk events may also result from *immediate causes*, such as a failure to apply basic knowledge, skills, or abilities or an operator impaired by drugs or alcohol. Figure 1 depicts the risk event error

[3] An allision occurs when a moving ship strikes a stationary object (other than another ship).

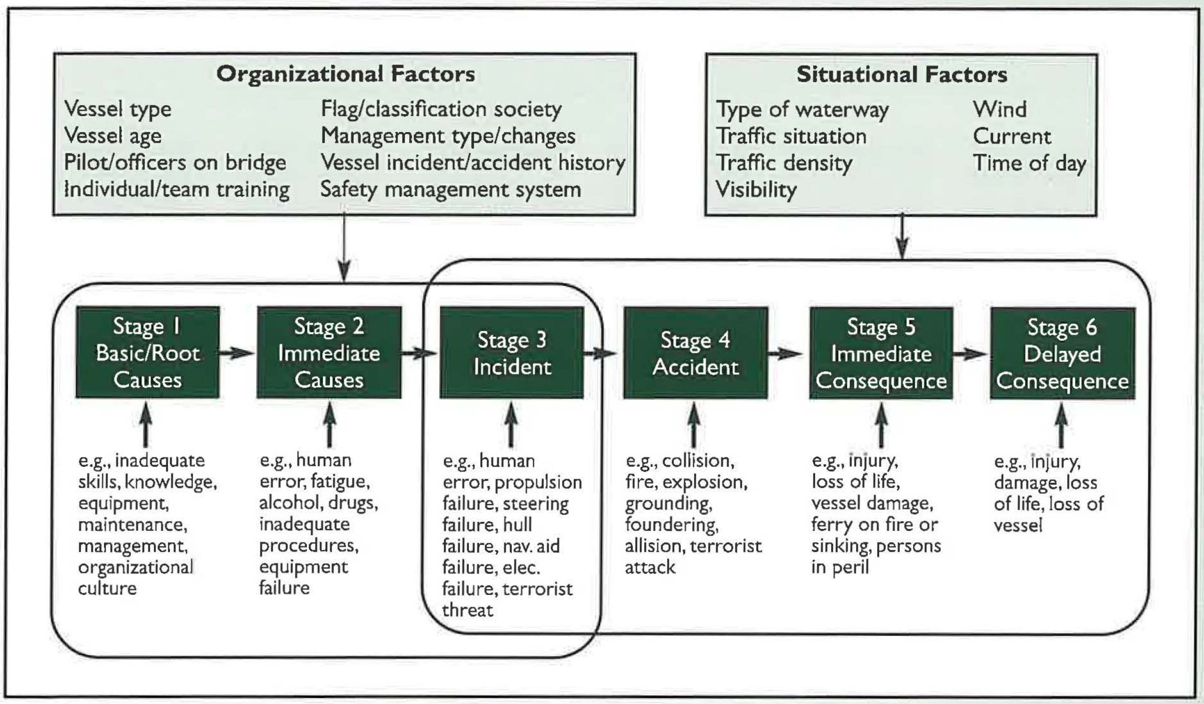


FIGURE 1 Risk event error chain (9).

chain. The figure illustrates the fact that risk events often occur because the error chain cascades: a basic cause can lead to an immediate cause, and an incident can trigger an accident. The key to risk mitigation is to manage risk in the system by introducing risk-reduction interventions at appropriate points in the error chain so as to prevent such a cascade (see Figure 2).

Guidelines for Effective Risk Assessment

In 1996 the National Research Council's Committee on Risk Assessment defined the process as "a synthesis and summary of information about a potentially hazardous situation that addresses the needs and interests of decision makers and of interested and affected parties." Risk assessment, suggested the committee, is "a prelude to decision making and depends on an iterative, analytic–deliberative process" (*10*: p.27).

To be useful, risk assessment should provide decision makers with information needed to make informed choices. The appropriate level of effort for a risk assessment and the choices made are situation specific, although the NRC committee noted two important elements: *careful diagnosis* of the situation to arrive at preliminary judgments, and *openness* to reconsidering those judgments as the process moves forward. The committee recommended that the procedures governing risk assessment remain flexible enough to be expanded or simplified to suit the needs of decision makers. Structuring an effective analytic–deliberative process to inform a risk decision, however, involves judgment. The NRC committee articulated five interrelated objectives for such a process.

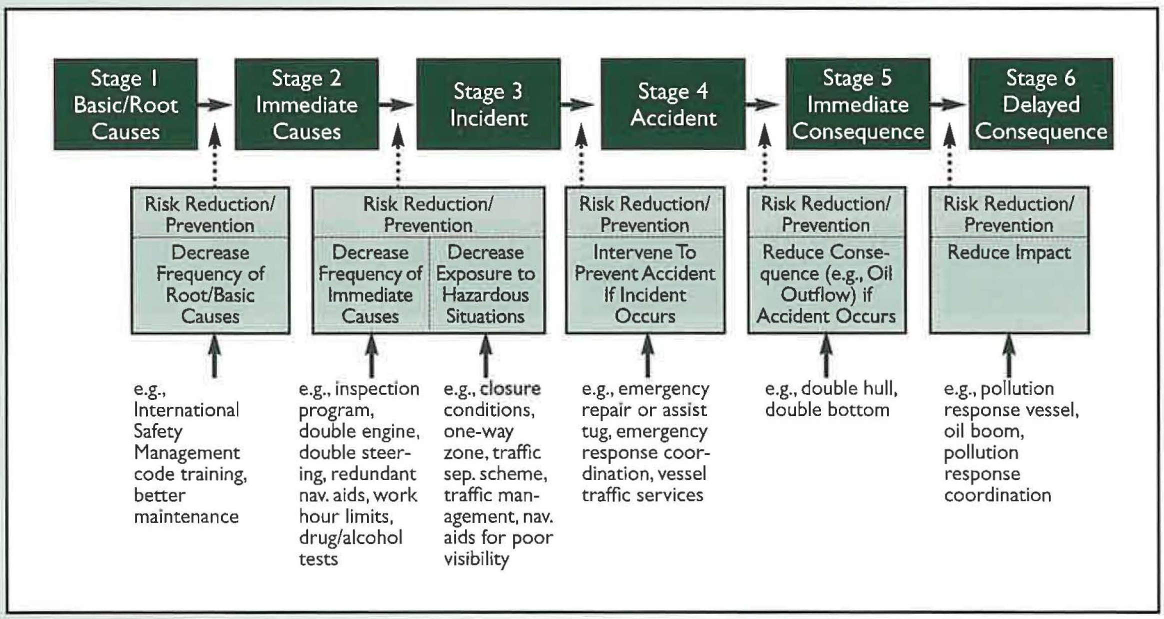
Get the Science Right

Getting the science right implies that the underlying analysis meets high scientific standards in terms of measurement, analytic methods, databases used, and plausibility of assumptions, considering any limitations placed on the analysis because of the level of effort judged appropriate. In practical terms, this means using a scientifically accepted risk assessment methodology, taking into account the importance of uncertain, incomplete, and unreliable information and its impact on the assessment.

Get the Right Science

Getting the right science means the risk analysis has addressed the significant risk-related concerns of public officials and the full spectrum of interested and affected parties. These concerns may include risks to health, safety, economic well-being, and ecological and social values, and analytic priorities are set so as to emphasize the issues most relevant to the decision. In marine transportation, this means ensuring that risk assessments focus on the risk-related priorities of public officials, marine transportation system members, other members of the ports and waterways community, regulators, and scientists, among others. Such priorities can be determined in a variety of ways, for example, through port and harbor safety committees; through analytic deliberations involving agency, public, industry, and environmental parties; and through listening sessions. Risk priorities should be articulated early in the assessment process and refined as required.

FIGURE 2
Risk reduction interventions (9).



Get the Right Participation

The analytic–deliberative process must have sufficiently broad participation to ensure that important, salient information enters the process, that all important perspectives are considered, and that the parties' legitimate concerns about inclusiveness and openness are addressed. In marine transportation, this means participation is sought from a variety of sources: shipping and towing company employees and operators; state, federal, and local regulators; ship's pilot organizations; ship's agents and representatives; insurers, brokers, and financiers; maritime interest groups representing all segments and types of waterway users and managers; the U.S. Navy; environmental and legal groups and representatives; and other interested and affected parties.

Various means can be used to involve these parties in the process, including formal and informal interviews; vessel rides and shore-based facility walkthroughs; data analysis; literature reviews; and participation in drills, exercises, and planning meetings. Risk analysts can then provide feedback to the various parties about the products and processes of the risk assessment. The NRC committee advised that it is often wiser to err on the side of overly broad rather than overly narrow participation, even though the process may be time-consuming and cumbersome, to ensure acceptance of the assessment's findings and enhance the likelihood that the resulting recommendations will be implemented.

Get the Participation Right

Both decision makers and interested and affected parties must be satisfied that the risk assessment process is responsive to their needs: that their information, viewpoints, and concerns have been accurately represented and taken into account; that they have been adequately consulted; and that their participation has affected the way risk problems are defined and characterized. System stakeholders should be identified during the risk assessment, and their participation requested. In marine transportation, vessel masters, mates, engineers, and pilots might be observed and interviewed aboard vessels, where problems and issues can be demonstrated. Moreover, shore-based management, operations, engineering, maintenance, and safety personnel might be interviewed in their places of work and consulted during the risk assessment, as might regulators; insurers; agents; brokers; shippers; environmental, legal, and special-interest groups; and other interested and affected parties.

Develop an Accurate, Balanced, and Informative Synthesis

Risk assessment is as much an art as a science. In marine transportation, the final synthesis of quantitative and qualitative information gathered during the assessment requires analytic and technological skills, domain knowledge (in this case, knowledge of safety-critical large-scale systems and maritime expertise), and the ability to communicate results in the context of uncertainty. Risk analysts must understand the importance of including the state of knowledge, uncertainty, and disagreement in the synthesis of a risk assessment, in addition to providing a careful analysis and presentation of the synthesized information.

Impacts of maritime accidents, such as fire or explosions, include death, injury, environmental damage, and economic losses. Introduction of risk-reduction interventions is key to managing risk.

The Future

The requirements for risk management in the 21st-century marine transportation system are not substantially different from those for other safety-critical large-scale systems, but do necessitate significant resource investments. These requirements include creation of system monitoring capabilities; development of information, planning, and leadership infrastructures; improvement of consequence management systems; and creation of organizational cultures that mitigate risk.

System Monitoring

Effective system monitoring requires periodic and ongoing risk assessment—characterizing the levels of risk in the system, identifying and assessing the effectiveness of various risk-reduction measures, and conducting dynamic assessments of current and future risks. Some efforts at improving system

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monitoring are in evidence throughout the United States and much of the international maritime world. In the 21st-century marine transportation system, such efforts must be institutionalized at the local, state or provincial, and national levels.

Information, Planning, and Leadership Infrastructure

Effective planning that mitigates risk in large-scale systems requires articulation of a vision for enhancing safety in the system; an information infrastructure that facilitates planning, scheduling, operation, maintenance, and refurbishment of system assets, including personnel; organizational resources to conduct the activities required to accomplish the vision; and the development of plans that ensure an optimal organizational response to emergency events.

An effective information, planning, and leadership infrastructure is critical to the success of a risk-averse marine transportation system. Such an infrastructure mitigates risk by:

- ◆ Requiring leaders to articulate a vision of enhanced safety and organizational performance.
- ◆ Providing adequate resources that enable the vision to be effectively carried out.
- ◆ Empowering middle managers to enact the safety practices that are critical to system success.
- ◆ Encouraging operational personnel to share the vision of high reliability and safety performance as system goals.
- ◆ Providing an information infrastructure that supports these tasks and responsibilities throughout the system, as well as planning and measurement processes that reinforce system goals and priorities.

These elements are present to varying degrees in the U.S. and international marine transportation systems, but will be essential for the 21st century.

Consequence Management Systems

In the United States, many organizations have undertaken initiatives to improve crisis and disaster management response, particularly in light of the maritime disasters of the current decade. More remains to be done, however, particularly for the marine transportation system of the future. These improvements include continuous assessment of meaningful, interactive, multi-organizational emergency response drills; improved crew training in the development of detailed emergency procedures; improved communication and accounting procedures and capabilities during an emergency; and improved, clearly visible, and easily understood emergency instructions and procedures.

Organizational Culture

Generally, high-performance systems are characterized by prioritized safety and reliability goals and standards designed to enhance a milieu of safe operations. Such goals and standards are often implemented through redundancy in personnel and technology. High-performance systems are also noted for having a shared organizational culture of reliability that is decentralized and constantly reinforced, often through continuing practice and training. Finally, high-performance systems generally manifest a high degree of interpersonal trust, which is fostered and developed through training, drills, and efforts designed to encourage people to get to know one another. Realizing these characteristics in the 21st-century marine transportation system requires:

- ◆ Renewed attention and resources devoted to training, drills, and procedures.
- ◆ Continuous assessment of the interaction among crew schedules, manning levels, and fatigue in the system.
- ◆ Attention to maintenance and repair planning, scheduling, and facilities.
- ◆ An information infrastructure that facilitates effective communication of safety- and efficiency-critical information.
- ◆ The provision of adequate resources throughout the system's life cycle (i.e., from resource planning to equipment building/procurement, asset operation, maintenance, repair, refurbishment, replacement, and retirement).
- ◆ A performance evaluation system that is linked to high-performance system goals and incentives, and the use of these metrics for continuous process improvement.

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