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MARITIME SAFETY MANAGEMENT: IMO´s METHODOLOGY OF THE RISK-BASED ASSESSMENT

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Introduction. One of the most significant objectives of the International Maritime Organization (IMO) in the 2000s is a introduction risk-based analysis and cost benefit assessment as a tool for use in the IMO rule-making process, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property. This structured and systematic methodology was named Formal Safety Assessment (FSA) and the Guidelines for FSA was approved by the Maritime Safety Committee and the Marine Environment Protection Committee for use in the IMO rule-making process, at April 2002. The FSA is a rational and systematic process for assessing the risks relating to maritime safety and the protection of the marine environment and for evaluating the costs and benefits of IMO’s options for reducing these risks. Application of FSA may be particularly relevant for proposals for regulatory measures which have far reaching implications in terms of costs to the maritime industry or the administrative or legislative burdens, which may result. This is achieved by providing a clear justification for proposed regulatory measures and allowing comparison of different options of such measures to be made. This is in line with the basic philosophy of FSA in that it can be used as a tool to facilitate a transparent decision-making process. In addition, it provides a means of being proactive, enabling potential hazards to be considered before a serious accident occurs.

General principles. Process of FSA should comprise the following steps: 1. Identification of hazards; 2. Risk analysis; 3. Risk control options (RCO); 4. Cost benefit assessment; 5. Recommendations for decision-making. The process begins with the decision makers defining the problem to be assessed along with any relevant boundary conditions or constraints. These are presented to the group who will carry out the FSA and provide results to the decision makers for use in their resolutions. Within the FSA methodology, step 5 interacts with each of the other steps in arriving at decision-making recommendations. The depth or extent of application of the methodology should be commensurate with the nature and significance of the problem. However, before starting the detailed application, a coarse application is suggested for the relevant ship type or hazard category, in order to include all aspects of the problem under consideration. Characterization of hazards and risks should be both qualitative and quantitative, and both descriptive and mathematical, consistent with the available data, and should be broad enough to include a comprehensive range of options to reduce risks. A hierarchical screening approach may be utilized. This would ensure that excessive analysis is not performed by utilizing relatively simple tools to perform initial analyses, the results of which can be used to either support decision-making (if the degree of support is adequate) or to scope/frame more detailed analyses (if not). The initial analyses would therefore be primarily qualitative in nature, with recognition that increasing degrees of detail and quantification will come in subsequent analyses as necessary. A review of historical data may also be useful as a preparation for a detailed study. For this purpose a loss matrix may be useful.

The human element is one of the most important contributory aspects to the causation and avoidance of accidents. Human element issues throughout the integrated system shown in figure 1 should be systematically treated within the FSA framework, associating them directly with the occurrence of accidents, underlying causes or influences. Appropriate techniques for incorporating human factors should be used. The human element can be incorporated into the FSA process by using human reliability analysis (HRA). Methodology for the use of HRA within FSA will be given in the next paper.

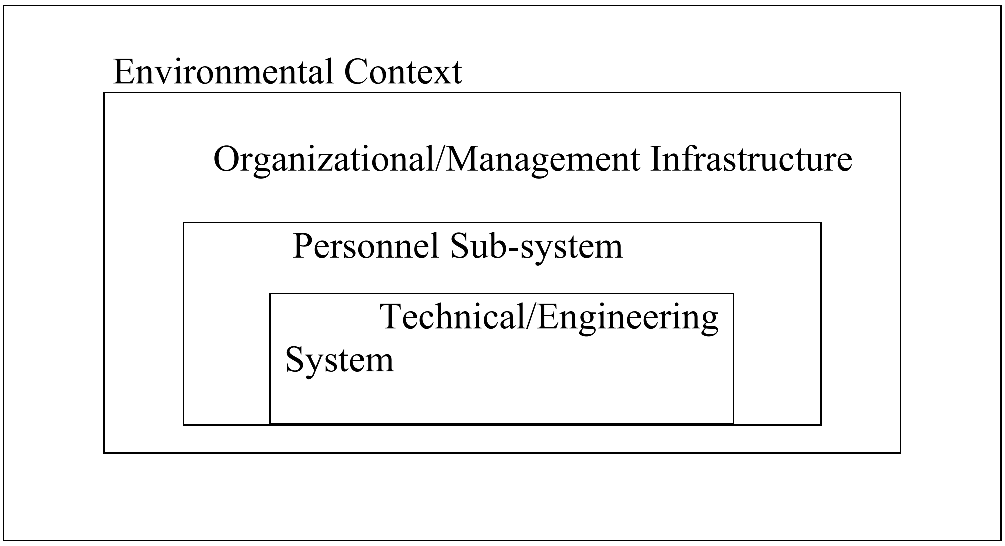

Fig. 1. Components of the integrated system

The definition of the problem should be consistent with operational experience and current requirements by taking into account all relevant aspects. Those which may be considered relevant when addressing ships (not necessarily in order of importance) are: (1) ship category (e.g. type, length or gross tonnage range, new or existing, type of cargo); (2) ship systems or functions (e.g. layout, subdivision, type of propulsion); (3) ship operation (e.g. operations in port and/or during navigation); (4) external influences on the ship (e.g. Vessel Traffic System, weather forecasts, reporting, routing); (5) accident category (e.g. collision, explosion, fire); and (6) risks associated with consequences such as injuries and/or fatalities to passengers and crew, environmental impact, damage to the ship or port facilities, or commercial impact. For application of FSA, a generic model should therefore be defined to describe the functions, features, characteristics and attributes which are common to all ships or areas relevant to the problem in question. The generic model should not be viewed as an individual ship in isolation, but rather as a collection of systems, including organizational, management, operational, human, electronic and hardware aspects which fulfill the defined functions. The functions and systems should be broken down to an appropriate level of detail. Aspects of the interaction of functions and systems and the extent of their variability should be addressed. A comprehensive view, such as the one shown in figure 1, should be taken, recognizing that the ship's technical and engineering system, which is governed by physical laws, is in the center of an integrated system. The technical and engineering system is integrally related to the passengers and crew, which are a function of human behavior. The passengers and crew interact with the organizational and management infrastructure and those personnel involved in ship and fleet operations, maintenance and management. These systems are related to the outer environmental context, which is governed by pressures and influences of all parties interested in shipping and the public. Each of these systems is dynamically affected by the others. The output of the problem definition comprises: (1) problem definition and setting of boundaries; and (2) development of a generic model.

FSA methodology steps.

Step 1. The purpose of step 1 is to identify a list of hazards and associated scenarios prioritized by risk level specific to the problem under review. This purpose is achieved by the use of standard techniques to identify hazards, which can contribute to accidents, and by screening these hazards using a combination of available data and judgement. The hazard identification exercise should be undertaken in the context of the functions and systems generic to the ship type or problem being considered, which were established early by reviewing the generic model. The analytical element ensures that previous experience is properly taken into account, and typically makes use of background information.

A coarse analysis of possible causes and outcomes of each accident category should be carried out by using established techniques (1. Fault Tree Analysis; 2. Event Tree Analysis; 3. Failure Mode and Effect Analysis (FMEA); 4. Hazard & Operability Studies (HAZOP); 5. What If Analysis Technique (SWIFT); 6. Risk Contribution Tree (RCT); 7. Influence Diagrams), to be chosen according to the problem in question. The identified hazards and their associated scenarios relevant to the problem under consideration should be ranked to prioritize them and to discard scenarios judged to be of minor significance. The frequency and consequence of the scenario outcome requires assessment. Ranking is undertaken using available data, supported by judgement, on the scenarios. A generic risk matrix is shown in figure 2.

The frequency and consequence categories used in the risk matrix have to be clearly defined. The combination of a frequency and a consequence category represents a risk level. Lowly there is provides an example of one way of defining frequency and consequence categories, as well as possible ways of establishing risk levels for ranking purposes The following table 1 gives an example of a risk matrix.

FREQUENCY

Frequent				HIGH RISK
Reasonably probable				
Remote				
Extremely remote	LOW RISK			
	Minor	**Significant**	**Severe**	**Catastrophic**

CONSEQUENCE

Fig. 2. Risk мatrix

Table 1. Risk Index (RI)

		SEVERITY (SI)			
		1	2	3	4
FI	**FREQUENCY**	Minor	Significant	Severe	Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

At the end of step 1, hazards are to be prioritized and scenarios ranked. Scenarios are typically the sequence of events from the initiating event up to the consequence, through the intermediate stages of the scenario development. To facilitate the ranking and validation of ranking, it is generally recommended to define consequence and probability indices on a logarithmic scale. A risk index may therefore be established by adding the probability/frequency and consequence indices. By deciding to use a logarithmic scale, the Risk Index for ranking purposes of an event rated remote. (FI=3) with severity. Significant. (SI=2) would be RI=5. Risk = Probability x Consequence. Log (Risk) = log (Probability) + log (Consequence).

Step 2. The purpose of the risk analysis in step 2 is a detailed investigation of the causes and consequences of the more important scenarios identified in step

1. This can be achieved by the use of suitable techniques that model the risk. This allows attention to be focused upon high risk areas and to identify and evaluate the factors which influence the level of risk. Different types of risk (i.e. risks to people, the environment or property) should be addressed as appropriate to the problem under consideration. The construction and quantification of fault trees and event trees are standard risk assessment techniques that can be used to build a risk model. An example of a conceptual risk model is the Risk Contribution Tree (RCT). Whilst the example makes use of fault and event tree techniques, other established methods could be used if appropriate.

Step 3. The purpose of step 3 is to propose effective and practical RCOs comprising the following four principal stages: (1) focusing on risk areas needing control; (2) identifying potential risk control measures (RCMs); (3) evaluating the effectiveness of the RCMs in reducing risk by re-evaluating step 2; and (4) grouping RCMs into practical regulatory options. Step 3 aims at creating risk control options that address both existing risks and risks introduced by new technology or new methods of operation and management. Both historical risks and newly identified risks (from steps 1 and 2) should be considered, producing a wide range of risk control measures. Techniques designed to address both specific risks and underlying causes should be used. The purpose of focusing risks is to screen the output of step 2 so that the effort is focused on the areas most needing risk control. The main aspects to making this assessment are to review: (1) risk levels, by considering frequency of occurrence together with the severity of outcomes. Accidents with an unacceptable risk level become the primary focus; (2) probability, by identifying the areas of the risk model that have the highest probability of occurrence. These should be addressed irrespective of the severity of the outcome; (3) severity, by identifying the areas of the risk model that contribute to highest severity out comes. These should be addressed irrespective of their probability; and (4) confidence, by identifying areas where the risk model has considerable uncertainty either in risk, severity or probability. These uncertain areas should be addressed. Structured review techniques are typically used to identify new RCMs for risks that are not sufficiently controlled by existing measures. These techniques may encourage the development of appropriate measures and include risk attributes and causal chains. Risk attributes relate to how a measure might control a risk, and causal chains relate to where, in the "initiating event to fatality" sequence, risk control can be introduced. The prime purpose of assigning attributes is to facilitate a structured thought process to understand how an RCM works, how it is applied and how it would operate. Attributes can also be considered to provide guidance on the different types of risk control that could be applied. Many risks will be the result of complex chains of events and a diversity of causes. For such risks the identification of RCMs can be assisted by developing causal chains, which might be expressed as follows: *causal factors → failure → circumstance → accident → consequences.* The output from step 3 comprises: (1) a range of RCOs which are assessed for their effectiveness in reducing risk; and (2) a list of interested entities affected by the identified RCOs.

Step 4. The purpose of step 4 is to identify and compare benefits and costs associated with the implementation of each RCO identified and defined in step 3. A cost benefit assessment may consist of the following stages: (1) consider the risks assessed in step 2, both in terms of frequency and consequence, in order to define the base case in terms of risk levels of the situation under consideration; (2) arrange the RCOs, defined in step 3, in a way to facilitate understanding of the costs and benefits resulting from the adoption of an RCO; (3) estimate the pertinent costs and benefits for all RCOs; (4) estimate and compare the cost effectiveness of each option, in terms of the cost per unit risk reduction by dividing the net cost by the risk reduction achieved as a result of implementing the option; and (5) rank the RCOs from a cost-benefit perspective in order to facilitate the decision making recommendations in step 5 (e.g. to screen those which are not cost effective or impractical). Costs should be expressed in terms of life cycle costs and may include initial, operating, training, inspection, certification, decommission etc. Benefits may include reductions in fatalities, injuries, casualties, environmental damage and clean-up, indemnity of third party liabilities, etc. and an increase in the average life of ships. Using various methods and techniques can carry out the evaluation of the above costs and benefits. There are several indices which express cost effectiveness in relation to safety of life such as Gross Cost of Averting a Fatality (Gross CAF) and Net Cost of Averting a Fatality (Net CAF) as follows. Gross CAF = $\Delta C / \Delta R$ and Net CAF = $\Delta C - \Delta B / \Delta R$, where: ΔC is the cost per ship of the risk control option. ΔB is the economic benefit per ship resulting from the implementation of the risk control option (this may also include pollution prevented). ΔR is the risk reduction per ship, in terms of the number of fatalities averted, implied by the risk control option.

Step 5. The purpose of step 5 is to define recommendations, which should be presented to the relevant decision makers in an auditable and traceable manner.

Conclusions. The recommendations would be based upon the comparison and ranking of all hazards and their underlying causes; the comparison and ranking of risk control options as a function of associated costs and benefits; and the identification of those risk control options which keep risks as low as reasonably practicable. The basis on which these comparisons are made should take into account that, in ideal terms, all those entities that are significantly influenced in the area of concern should be equitably affected by the introduction of the proposed new regulation. However, taking into consideration the difficulties of this type of assessment, the approach should be, at least in the earliest stages, as simple and practical as possible. Recommendations should be presented in a form that can be understood by all parties irrespective of their experience in the application of risk and cost benefit assessment and related techniques. Those submitting the results of an FSA process should provide timely and open access to relevant supporting documents and reasonable opportunities for, and a mechanism to, incorporate comments.

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