LINKING RISK ASSESSMENT OF MARINE OPERATIONS TO SAFETY MANAGEMENT IN PORTS

Dr. Vladimir M. Trbojevic
EQE International Ltd
ABS Consulting
ABS House
1 Frying Pan Alley
London E1 7HR
United Kingdom
Tel: +44 20 7377 4577
Fax: +44 20 7377 4575
Email: vmt@eqe.co.uk

ABSTRACT

An approach for developing Integrated Safety Management System (ISMS) for managing navigation and other marine operations in ports is proposed. The methodology requires that all risks are identified and evaluated, that suitable controls are in place to manage these risks, and that the linkage between risk controls, operating procedures, harbour by-laws, and the management activities is explicitly established. This methodology has been applied to a number of ports in the UK in compliance with the Port marine Safety Code requirement, [1]. An extension of the methodology towards assessing focus and robustness of the ISMS is also discussed, and some ideas about "safety rating" of ISMS are presented.

INTRODUCTION

As a consequence of the Sea Empress disaster in Milford Haven in 1988, the Port Marine Safety Code (PMSC) was introduced in the UK IN March 2000, requiring all ports to carry out risk assessment of marine operations in order to implement the safety management system, [1]. Deadline for implementation of the PMSC is the end of 2001. Considering that ports are at the onset of safety regime utilised in other industries (e.g. Safety Report / Case regime), a suitable risk assessment methodology has been proposed which can easily be understood by all stakeholders in a port, [2].

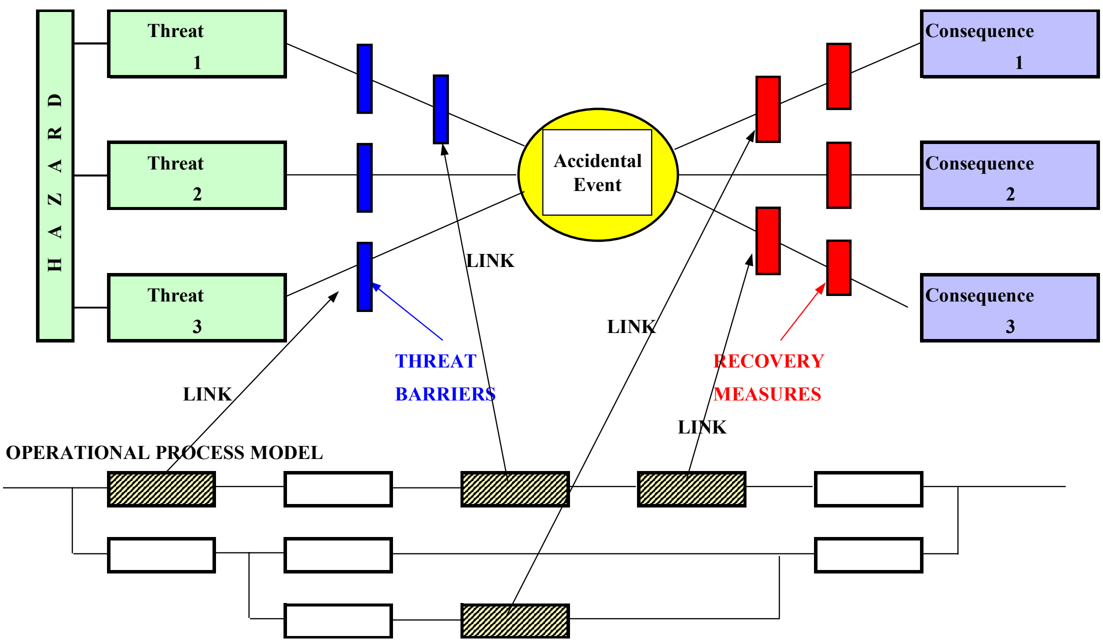
This methodology has been inspired by increasingly obvious shortcomings in existing safety technology, in lack of information transfer from hazard identification and risk assessment through to the safety management system. This means that a link between the technical system description (risk model) and the demonstration of working of the management system in the context of major hazards control is often weak. This is not unusual because the methodologies for hazard analysis and risk assessment, in general, do not deal with complex technical and organisational systems in a unified manner. For example, the quantitative risk assessment (QRA) may account for operator error, and the quality of organisation and management by modifying human error failure rates, however to incorporate the “probability of partial malfunction of the emergency system” is hardly ever done.

In the proposed methodology, it is possible to include competency, personnel training, the establishment of operational constraints, supervision, communication and information exchange, etc. into the risk model.

THE ESSENCE OF THE APPROACH

The Integrated Safety Management System (ISMS) is the final objective of this risk analysis. It is called an “integrated” system because it explicitly links through risk controls, the hazard analysis of the technical system to the safety management of all processes in a port. Such an “integrated” system is shown graphically in *Figure 1*.

Figure 1 A Basis for ISMS Model



The main components of this ISMS are:

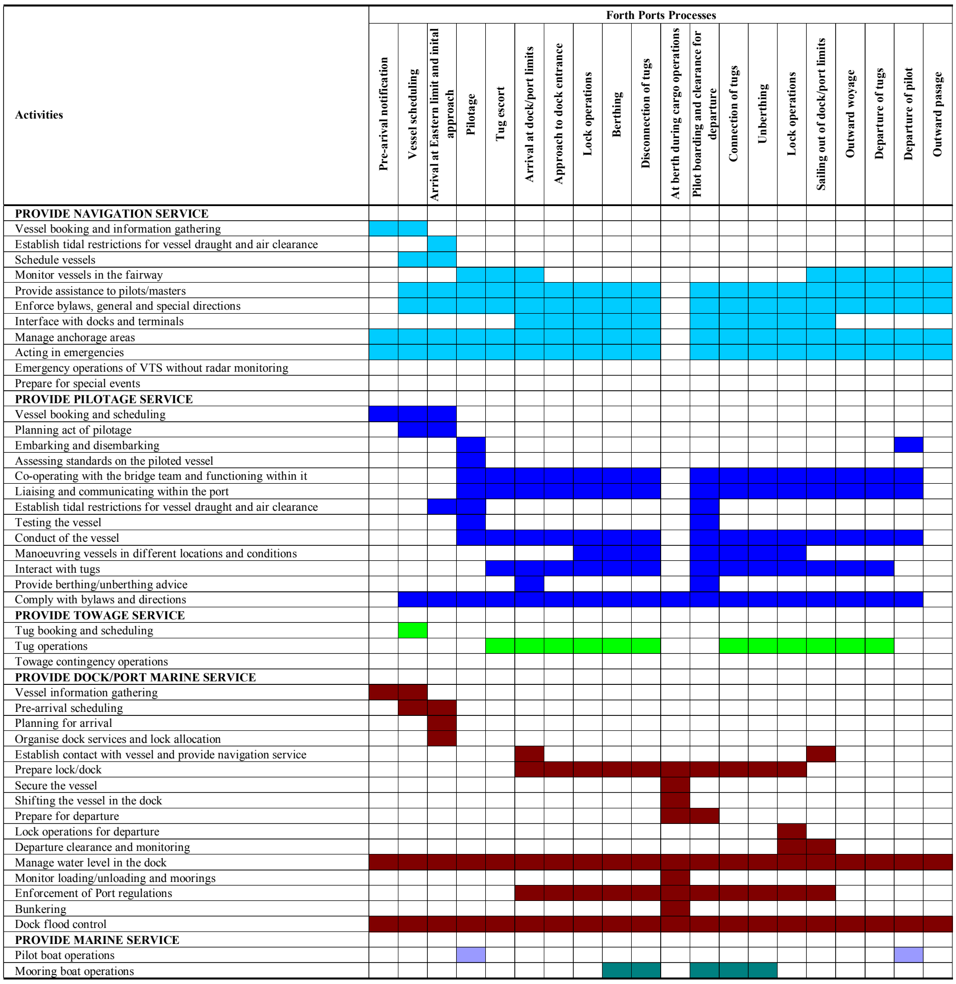
- The risk assessment represented by a bow tie (diagram in *Figure 1*), that represents the hazard and the barriers which if breached could lead to an accidental event (situation), which could escalate to unwanted consequences if the recovery measures are not in place,
- The operational process model represented by activities and tasks port personnel have to carry out on day to day basis, and
- The links between hazard barriers and recovery measures and tasks of port personnel.

Some of the activities (and tasks) are “safety critical” and they integrate the safety objectives, strategy and review at the senior management level, operating procedures at a technical support level, regulations, responsibilities related to planning and executing work at an operational level, and at task level, the responsibility for direct management of hazard barriers and recovery measures. Adding the management objectives for the activity, management accountability, performance indicators and performance criteria, task responsibility and required competence, the basic blocks of ISMS are established.

Establishment of the Process Model

The process model is developed by mapping activities and tasks. The activities were classified as related to management (A), operations (B) and support (C). The activity models, and in particular model for operational activities (B) were developed in conjunction with risk assessment, i.e. in several iterations. Within each activity there is a set of tasks, and the starting point was to define an activity for each of the main processes, e.g. VTS, pilotage, towage, docks/ports, pilot cutter, linesmen, etc. At later stages, due to a large number of tasks, “sub activities” were defined for each main activity, as shown in *Figure 2*.

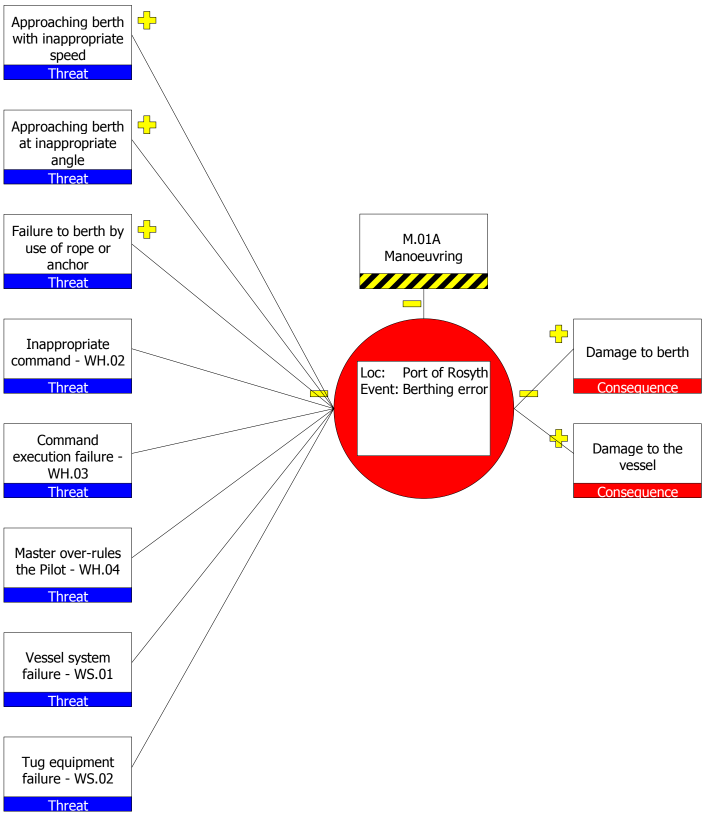
Figure 2 Processes and Activities



Development of a Risk Model

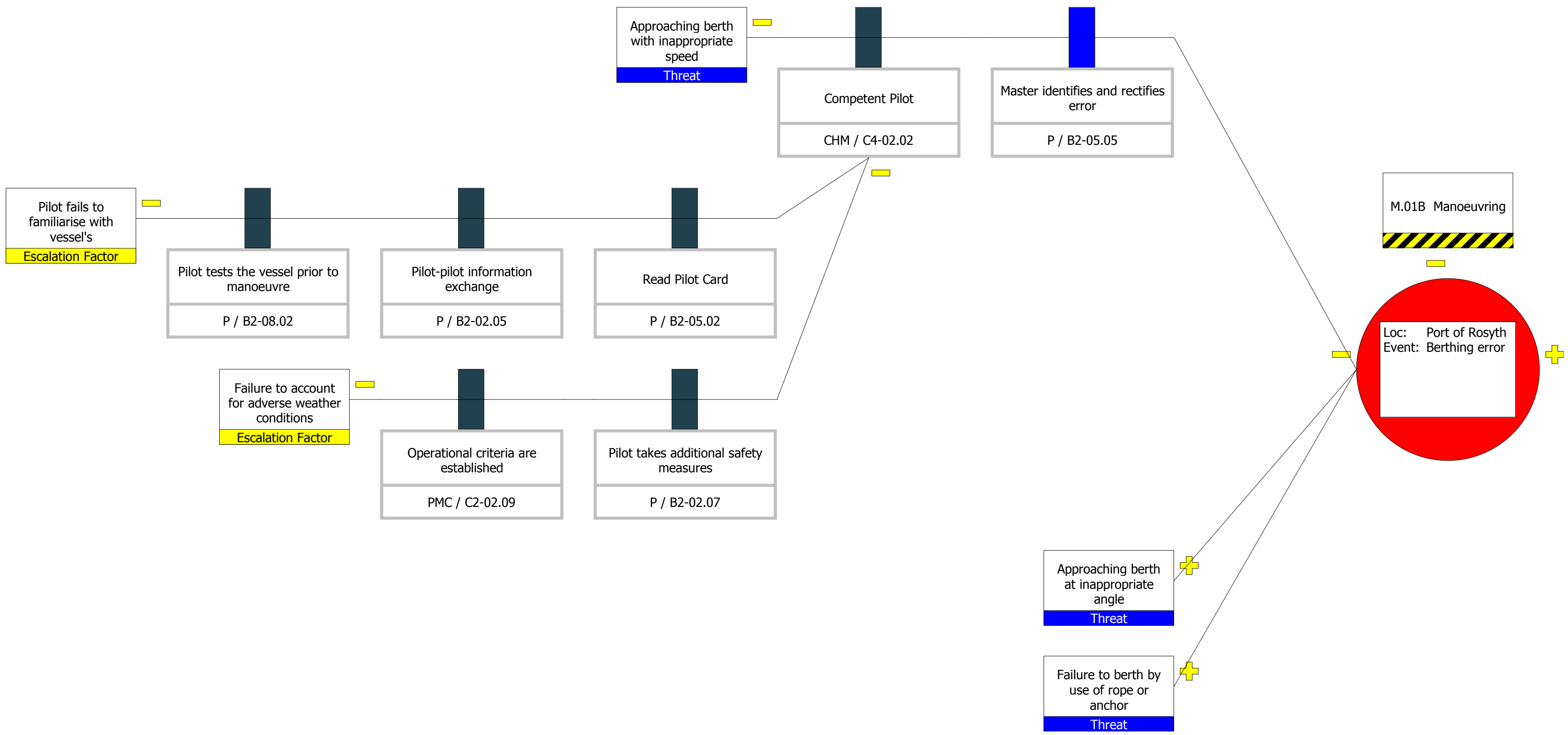
The risk analysis approach was described in [2] and is briefly summarised here. In this approach it is assumed that each specific hazard can be represented by one or several threats that have the potential to lead to an incident or accidental event. Each accidental event may lead to unwanted consequences. In the example shown in *Figure 3*, top event is "berthing error" (defined as a failure to berth the vessel safely, due to approaching the berth with excess speed, or approaching the berth at an inappropriate angle, or giving an inappropriate command, or due to command execution failure, etc.). Consequences of this failure can be collision with the berth or another vessel, vessel damage, etc.

Figure 3 Berthing Error Event



For each threat one or several barriers can be specified to prevent or minimise the likelihood of hazard release. In the example in *Figure 4*, barriers to the threat of "approaching berth with inappropriate speed" are "Competent Pilot" and "Competent Master". For any barrier there may be internal or external factors which influence its effectiveness, for example, a competent pilot may have failed to familiarise with the vessel manoeuvrability, say due to commercial pressure, or he may have under-estimated weather effects due to lack of operational criteria in the port. These barrier failure modes are be modelled as "escalation factors" each of which can be controlled by "escalation factor control", *Figure 4*. The escalation factor controls can be envisaged as secondary barriers; for example, if the master has not familiarised himself

Figure 4 Barriers and Recovery Measures



with the vessel, he should "test the vessel before each manoeuvre" or he should discuss vessel's behaviour with other pilots, i.e. "pilot-to-pilot information exchange", etc. Similarly, in the absence of operational criteria, pilot should be empowered to "take additional safety measures", for example, tugs. Any threat should have a sufficient number of barriers and escalation factor controls to ensure the integrity of the system.

If a hazard is released, the accidental event can escalate to one of the several possible consequences. To prevent escalation, the mitigation measures, emergency preparedness and escalation control measures need to be in place to stop chain of event propagation and/or to minimise the consequences of escalation. Each of these recovery measures can be associated with one or several failure modes, or escalation factors; for example, tug support may not be effective due to tug failure or wind and current effects. Control measures can be specified to prevent or minimise these failures.

Matching Tasks to Barriers

With the preliminary risk model and the list of tasks, an attempt was made to match the tasks to barriers. Logic was very simple, most of the task that people do, for example, to get the vessel safely to the berth, are safety related, and therefore should match corresponding barriers or recovery measures in the risk model. This matching or linking of tasks and barriers is shown in *Figure 4*. For example, part of pilot's familiarisation with the vessel is to read the "Pilot Card" which is also one of the barriers; in the lower part of the barrier box the post indicator is given of a person responsible for this task ("P" stands for pilot), and the number B2-05.02 denotes activity (B2-05) and the task (02).

After the first iteration, interestingly, this matching was far from complete. The number of barriers and recovery measures exceeded the list of tasks. There is nothing unusual about this, as port personnel were not used to think in a "systems" manner, and were also unfamiliar with risk analysis. The benefits of working as a team started to materialise, as it became obvious that a risk analyst was "up to something", and the missing tasks were quickly established. In trying to identify the tasks and match these with the barriers, port personnel were also buying into risk analysis. Very soon they were coming up with all kinds of additional barriers, and the team "bonding" was complete.

The further iterations followed the same pattern starting from an updated list of tasks and the revised risk model which included additional barriers. The number of brain storming sessions with port personnel was between four to six per port. The number of tasks increased from originally identified 150 to between 500 and 600.

Risk Assessment

In this type of qualitative risk analysis, risks are assessed by establishing consequence severity and then estimating the likelihood of the consequence. This was done by using risk matrix shown in *Figure 5*. Colouring of fields in the risk matrix suggests three regions of risk, a broadly acceptable zone (white) where risks only require to be managed for continuous improvement, an intermediate zone (yellow) in which risks are only acceptable if it is demonstrated that they are As Low As Reasonably Practicable (ALARP), and an intolerable zone (red).

Figure 5 Risk Matrix

Consequences					Increasing Likelihood >					
People	**Assets**	**Environment**	**Reputation**		**Not heard of in ports industry**	**Has occurred in ports industry**	**Has occurred in PoT**	**Happens several times per year in ports industry**	**Happens several times per year in PoT**	**Happens every day**
					A	**B**	**C**	**D**	**E**	**F**
No injury	No damage	No damage	No impact	**0**	**A0**	**B0**	**C0**	**D0**	**E0**	**F0**
Slight injury	Slight damage	Slight effect	Slight impact	**1**	**A1**	**B1**	**C1**	**D1**	**E1**	**F1**
Minor injury	Minor damage	Minor effect	Limited impact	**2**	**A2**	**B2**	**C2**	**D2**	**E2**	**F2**
Major injury	Local damage	Localised effect	Considerable impact	**3**	**A3**	**B3**	**C3**	**D3**	**E3**	**F3**
Single fatality	Major damage	Major effect	National impact	**4**	**A4**	**B4**	**C4**	**D4**	**E4**	**F4**
Multiple fatalities	Total loss	Massive effect	International impact	**5**	**A5**	**B5**	**C5**	**D5**	**E5**	**F5**

This approach is in line with the British safety legislation, which allows an operation to proceed if the risks are reduced to the level that is as low as reasonably practicable. In other words, if the benefits of risk reduction exceed the cost of remedial measures, then these measures have to be implemented.

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Risk Acceptance Criteria

Risk assessment is carried out by comparing the risk (based on the likelihood of unwanted consequence) and the available risk control measures (barriers and recovery measures). In this approach the acceptance of risk is based on the number and the quality of risk controls against the estimated risks, as shown in *table 1*. The acceptance requirement based on the redundancy of barriers is also a "sanity check", since having one barrier in the tolerable (alarp) zone is against safety logic of defence in depth, hence the proposed criteria require two barriers. The required number of barriers in *table 1* represents the minimum required.

Demonstration of ALARP in this approach was based on the following:

- The fact that ports have been operating for many years and that risk of fatalities has never been an issue in marine operations in ports, and by review of historical accident data and comparison with risks in other industries, it has been concluded that risk of fatalities is low, and already tolerable; and

- The demonstration that all identified risk controls are in place and linked to people who operate or maintain these; therefore personnel awareness and appreciation of hazards and risks is achieved and the responsibilities related to safe operation are clearly defined.

Table 1 Risk Acceptance Criteria

Region		Criteria
ALARP	1	Requires a minimum of two effective barriers in place for all threats
	2	Requires a minimum of one effective recovery measure (barrirer) for each identified consequence
	3	Requires a minimum of one effective control in place for all escalation factors
Intolerable	1	Requires a minimum of three effective barriers in place for all threats
	2	Requires a minimum of two effective recovery measures (barriers) for each identified consequence
	3	Requires a minimum of one effective control in place for all escalation factors

SAFETY RATING

Having demonstrated ALARP and developed the basis for the ISMS, the next step was to explore the idea of assessing the safety effectiveness (quality) of the ISMS. The quality of a safety management system is typically assessed through audits; by going around the "plan-do-check-feedback" loop for processes and activities, their completeness is investigated (and sometimes quantified numerically). Therefore, if for every activity there is a policy or plan related to safety, evidence that it has been implemented and checked by measurement of performance, and that the results of checks/measurements are followed up by the management, then the loop is complete, and consequently the "score" is high, [3].

However, the measure of safety of marine operations in two fictitious (similar) ports with the same audit score of their management systems, will not be the same. Three parameters have been proposed in [3], the focus of the safety management system (linkage to hazard controls), fitness for purpose (quality of command, management and maintenance of those controls), and robustness (safety effectiveness) of the system. An attempt to assess some of these parameters is described here.

Focus of the ISMS

This parameter deals with the completeness of the links between the safety equipment and procedural controls and the elements of the safety management system. This requires detailed identification of hazards and the related risk controls, which can be achieved with the proposed approach. Hence a comparison of the risk models of the two fictitious ports would provide indication about the focus of their management systems, as one port may have more barriers than the other.

Assessing the Fitness for Purpose of the ISMS

This parameter can be assessed by audits based on the "plan-do-check-feedback" loops, and will not be discussed here. It deals with the quality component of the system.

Assessing the Robustness of the ISMS

The robustness of a system can be measured by the number and quality of safeguards. The first step towards this goal is embodied in the risk acceptance criteria, *Table 1*. The second step can be achieved by assessing the quality of safeguards in terms of the "safety effectiveness" of risk controls. Factors that influence the level of effectiveness of a risk control (barriers or recovery measure) are its reliability, its effectiveness, level of experience and training, amount of control over it, etc. An example of the barrier effectiveness levels is presented in *Table 2*.

Table 2 Barrier (Recovery Measure) Effectiveness Levels

Level	Description
1	Barrier is not directly efective, e.g. this type of barrier woud not prevent hazard from escalation towards top event
2	Fairly reliable barrier - reliable performance with limitations in certain situations, or a barrier outside direct control of the Forth Ports
3	Effective barrier - reliable performance with a possibility of slight errosion in decision making or effectiveness; possible improvements in training
4	Very effective barrier - very reliable performance without any erosion in decision making or effectiveness; high level of training and competence
5	Very effecive barrier with all escalation factors covered by several escalation factor controls (secondary barriers)

The next step is to establish rule set for barrier rating. This can be done either in discussion with the Harbour Master, pilots, and port personnel, as shown in *Table 3*, or by an audit approach where strengths and weaknesses of the control and monitoring loops of the organisation and management of navigation are assessed. The process investigates whether the loop is complete, and rates individual activities within the system, [4]. The barrier effectiveness level is then modified accordingly.

With the above approach the average rating of barriers obtained for a number of ports was within the range of 2.5 and 4, and the recovery measures between 1 and 3.

Table 3   Example of Rule Set for Barrier Rating

Barrier Type	Barrier Description	Effectiveness
Independent active		
	Competent Pilot	4-5
	Competent Master	3-4
Independent passive		
	Vetting vessel schedule	2-3
	Pilot-Master information exchange	2-3
	Requirement to declare draught	3-4
	Safety margin provided by UKC	3
	Reporting at reporting points	3
Operational criteria		
	Minimum air clearance	4
	Weather criteria	4-5
Warnings		
	VTS broadcast warning to shipping	3-4
	Positive warning of strong winds	3-4
Deterrent		
	Report vessel to MCA	0-1
	Reporting near misses	2-3
Etc.		

CONCLUSIONS

A more explicit, visible and demonstrable coupling of hazard controls and defences, and the port marine personnel responsibility to comply with or ensure the effectiveness of these controls is presented. The main advantages of this risk management approach are as follows:

- It is easily understood by all parties involved,
- Accountability and responsibilities are well defined,
- Involves every staff member in the risk management process and increases awareness to safety issues (in other words, everyone knows how is his/hers operational task linked to hazard controls),
- Risk management can be demonstrated to other stakeholders, customers, regulators, general public and insurers.

In addition, the overall rating of the safety management system can be carried out, and comparison made with other ports. The advantages of this type of rating are:

- It provides clear indication of weaknesses in the system, and areas where risk remedial measures have to be implemented;
- It also provides an audit trail for the improvement of the navigational and operational safety in a port;
- It facilitates decision making about investment in ports.

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