LEARNING FROM EXPERIENCE – ADOPTING A SYSTEMS APPROACH TO THE ANALYSIS OF MARINE INCIDENTS

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SUMMARY

The continual development of the standards applied in the implementation of the classification process, the Rules, is based on maintaining pace with changes in maritime technology but it also reflects experience, both of successful application and of failures. There is often criticism that the maritime regulatory process, which essentially means the application of the international regulations developed by the International Maritime Organisation (IMO) and classification, is influenced too strongly by incidents. The regime is, therefore, reactive and does not prevent the future occurrence of marine incidents by anticipating possible failure scenarios. Nonetheless, the lessons gained from operational experience remain important as incidents frequently result from apparently unlikely combinations of factors and it seems that even the most comprehensive paper study often fails to predict the combinations which come into play. In this paper the authors present a "systems approach" to incident analysis as a practical methodology by which the learning potential from incidents can be maximised. Some well-known incidents are reassessed, which suggest that more information can be gleaned, including causal factors which may otherwise be missed. From a classification society perspective it is important that incident analysis is searching and comprehensive so that appropriate mitigation measures can be developed to reduce the risk of recurrences.

1. INTRODUCTION

In this paper the authors are principally commenting on the evaluation of evidence from marine incidents in such a way that the maximum useful information is extracted to support the development of effective risk control measures through regulation and standards.

The authors of this paper recognise that ships and marine systems are becoming more complex and integrated, and a "system" includes its operators. Improvements in operational safety can be achieved by dealing with the "relevant systems" that support operation. This view requires a different way of abstracting information from incident data.

The methodology presented in this paper provides a structured "systems approach" which leads to the clear identification of the initiating points where a corrective action either in terms of regulation or operational procedure could reduce the associated risk, effectively and specifically.

In presenting some reassessment of the information that has been presented in publicly-available formal and informal incident reports, there is no criticism intended of the investigators or their conclusions. However, by using the same base data the authors demonstrate that other valuable information can be elicited, which could be important in preventing future different incidents.

2. LEARNING FROM INCIDENTS – NECESSITY AND EFFECTIVENESS

2.1 NECESSITY

The history of industrialised society is littered with examples where early warnings of hazards were ignored until sufficient hard evidence had been accumulated, often a very long time later. Some good illustrative examples are described by the European Environment Agency (EEA) [1] in a report which is based around the following four questions:

- When was the first credible scientific "early warning" of potential harm?
- When and what were the main actions or inactions on risk reduction taken by regulatory authorities and others?
- What were the resulting costs and benefits of the actions and inactions, including their distribution between groups and across time?
- What lessons can be drawn that may help future decision-making?

The concept promoted by the EEA authors is one of precaution, and the evidence supports the argument that industrial society is not good at taking cognisance of early warnings, foreseeing future impact and forestalling the inevitable consequences.

Given the application of the 'precautionary principle' in marine legislation, the discussion by the EEA authors on the need to address risk, ignorance and uncertainty is relevant to the maritime community, as is the discussion on the 'level of proof' required to justify action.

2.2 EFFECTIVENESS

2.2(a) Access to data

It is often assumed that most lessons from incidents will necessarily come from major events, which is generally assumed to be from those incidents that demand formal investigation and reporting. These will usually involve loss of life or pollution, or the recognition that avoidance of either of these outcomes was fortuitous. Many similar incidents may not be reported in detail because the consequences were simply less dramatic. For instance, a loss of propulsion power at sea may require towing to a safe haven or repair at sea but a similar event close to shore or in the confines of a port can have far greater impact.

If the lessons learned from marine incidents are to be of the highest value in terms of prevention then it is imperative that information is gleaned from minor incidents as well as the major cases. This means access to formal investigations and informal, usually unpublished, work. In many cases minor incidents are simply not recognised as significant, and any corrective action is dealt with by the operator and, maybe, the equipment supplier without any expectation of providing a learning opportunity for the marine community. To develop the capacity of the marine industry to learn from incidents, consideration has to be given to formal investigations by flag administrations and others, damage investigations supported by scientific and engineering analysis and the collected wisdom of ships' staff, owners' superintendents, equipment suppliers and surveyors.

2.2(b) Data Collection

Careful and thorough data collection is essential for the effective analysis of incidents. This can be time consuming and is dependent on eliciting basic facts from all individuals who might have relevant knowledge. Data is also extracted from recording systems, written records and from technical investigations. For well over fifty years Lloyd's Register has benefited from the systematic investigations of failures which has been carried out by its own expert investigation team, known throughout the marine industry variously as the Engineering Investigation Department, Technical Investigations Department and now the Technical Investigations element of Consultancy Services. The reports of investigations carried out for marine clients are based on an assessment of available data and, usually, field measurements and supporting engineering analysis. In most investigations of incidents this level of investigative rigour is not found, with greater reliance on the records from operations and the recall of those involved.

The most accurate data is collected shortly after the incident, which requires access to people and the ship so that the investigators can proceed before data is lost or recollections become more distant. The investigators are faced with a number of inhibiting pressures which constrain the effectiveness of the all-important data collection stage. Incidents usually involve insurance claims and there is increasing likelihood of litigation, and of course the individuals involved will face the prospect of disciplinary processes and adverse consequences on their livelihood. Investigations may be necessary to support insurance claims or to satisfy legal or political demands but these purposes may, themselves, restrict the learning opportunities and reduce the overall effectiveness of incident analysis in terms of preventing the occurrence of similar incidents.

In some industries the adoption of a "blame free" and often confidential reporting scheme has resulted in the systematic collection of incident information although this necessarily suffers from a lack of substantive analysis of the facts. Some efforts have been made to introduce similar arrangements into the marine industry and these could be used to provide better early warning data, as individuals can report events which could have resulted in an incident but where circumstances precluded the full event development.

2.2(c) Reconstruction and Analysis

Without doubt the analysis of marine incidents provides an essential source of information to the regulators and operators. It follows that the incident reports must be credible, presenting well-analysed conclusions and recommendations. The scope of analysis and reporting is typically based around a few 'causes' and 'some contributing factors' – the 'causal field' is fairly narrowly drawn. There are some theoretical concerns with this, discussed in Section 4.

In practical terms however, it is unlikely that the maximum value can be extracted from an incident investigation if the conclusions and recommendations are specific to that incident and do not draw wider implications. The wider value may not sit comfortably in an incident report but the learning value would suggest that is is incumbent on the investigators to disseminate their findings, including facets which might not have been significant for the incident under investigation but nevertheless incident indicate the need for some form of corrective action. The phrase "learning from incidents" may be needed to complement "incident analysis" and is used here.

"Hindsight bias remains the primary obstacle to accident investigation, especially when expert human performance is involved" (Cook, [2]). Dekker [3] has highlighted the need to reconstruct people's unfolding mindset as central to the analysis process. For a valid understanding of how an incident came about, it is necessary to apply the approach to latent errors at the 'blunt end' as well as active errors at the 'sharp end'.

It would normally be expected for human and technical factors to occur in concert. Whilst assigning causes to factors such as these may aid understanding, they may actually impede learning from incidents. 'Loss of situation awareness' has appeared quite frequently in recent incident reports, brought about by factors ranging from loss of channel lights to the use of a mobile phone whilst on watch. Johnson [4] concludes "Most human factors' research is concerned with improving our understanding of human error. Very little of it can be directly applied to reduce the impact or frequency of those errors." From the point of view of encouraging corrective or improvement actions, it is desirable to link the analysis to models of good practice. In the case of the'sharp end' this would be a model of Crew Resource Management. Other models are appropriate to design offices, manufacturing facilities etc.

2.2(d) Information Presentation

Any incident investigation will result in a large volume of data, some of which has little relevance to the conclusions. Many incident reports are very detailed, lengthy and written for the expert professional. The need for a full narrative is not questioned, but for maximum benefit the incident and its precursors need to be interpreted for a wide audience. The use of some diagrammatic formats such as Fault Trees should be regarded as for the specialist only. The lessons learned must be presented so that the competent reader can draw conclusions of value.

Learning from incidents can only be effective if the learning outcomes are communicated effectively to the widest possible audience. It follows that there are benefits in adopting a format which is clear, logical and standard.

The logical approach to organising the information is user-centred i.e. by stakeholder. The understanding of the reader is significantly enhanced if he understands why things did happen that way; reconstructing the evolving mindset would appear to offer considerable value in this regard.

The importance of clear presentation is crucial when there are a number of links between systems and people. Of significance is identification of opportunities that were, for some reason, missed. This may be that information was not understood by the people involved or too much data was available and the interpretation placed on this was incorrect. Neither necessarily infers a lack of competence.

If the benefits of learning from incidents are to be achieved, then the information to be presented increases in scope considerably, to accommodate those shortfalls where there are lessons to be learned but which were deemed not to be among the causes or contributing factors.

3. NON-PROXIMATE CAUSES

It sometimes appears that investigations take a long time and the publication of the final report appears to be far after the event. In reality, investigators have to work quickly, before the evidence fades, and work patiently through the collected data. They need to consult with a large number of interested parties. They then have to reach conclusions which are robust and make recommendations which will have a significant impact if implemented effectively.

Since the focus is inevitably on a single incident it is not surprising that it is rare to find investigators making recommendations based on other than the proximate causes, which means that some information which could provide a learning opportunity is discarded as not relevant. Where prosecution is being pursued it is also the case that the investigators can do sufficient to achieve that aim but no more (of particular importance in relation to human error as a cause). The consequence of the various pressures on the investigators to get a quick result is that some of the less obvious but nevertheless important lessons are lost. The authors, in conducting some paper studies, have found a number of cases where opportunities for learning have been missed.

This happens also in informal investigations where the pressure is to find a solution to the problem and not to investigate, for instance, how the circumstances arose in the first place. As an example Fig 1 shows a broken section of shaft, with a keyway and a classic fretting fatigue fracture. The shaft mounted a flexible coupling, fitted on a taper and secured by a threaded retaining nut. Investigation identified that the cone angle of the taper was unusually large and this demanded a carefully controlled fitting procedure, which was not apparently followed. So the proximate cause of the failure is identified, but why did the designer choose the form employed and why was the fitting procedure not followed? In terms of avoiding recurrences these lessons might be important. It has become apparent that "drawing office rule of thumb" values have fallen into disuse and a number of cases where failure has resulted from details which would not satisfy these practices, with designers relying on calculations and analysis.

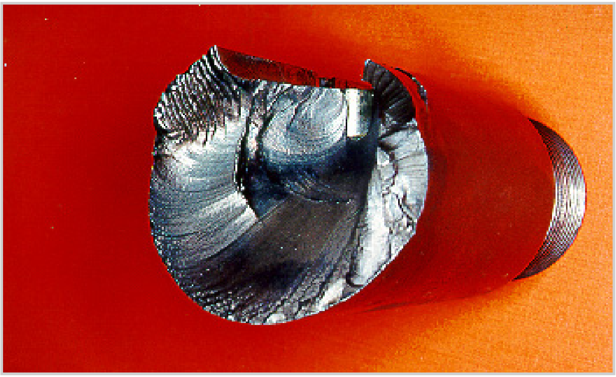

Fig 1 Failed coupling shaft

The authors believe that a great deal can be learned from studying the underlying factors in determining why things were done in a particular way. When a combination of factors is involved in an incident this can make it more difficult to establish why decisions were made but, with an industry reliant on sub-contracting and increasingly complex systems, understanding the issues involved can help the regulator to decide where the most appropriate risk control measures can be targeted.

4. STRUCTURED ANALYSIS USING A "SYSTEMS APPROACH"

A small literature has been identified that takes a systems approach to accident causation and analysis. It is not homogeneous. The authors have taken a systems approach in the following respects:

- Relevant systems have been identified (see Annex A) and treated as systems.
- A systems (rather than mechanistic) approach to causation is taken (see Annex B).

The approach to incident analysis adopted by the authors makes use of a spray diagram [5] or 'mind-mapping' format. This presents the data in an informal but structured form that is very compact. It also allows links to be drawn between the various elementary causal factors and for links to be brought together in standard groups.

This particular incident analysis activity does not need to identify the specific causal sequences or logic, enabling the use of simpler diagrams. It is recognised that this format may not suit all phases of incident analysis.

The format bears some similarities to accepted methods such as TRIPOD [6], event trees and fault trees. The reasons for adopting this particular format were:

- Simplicity and ease of understanding.
- It draws out the multi-agent nature of accident causation and identifies the main groups of agents through the life cycle.
- By focusing on the main groups of agents, the format is user-centred and allows the reader to concentrate on their particular area of interest.
- It enables cause and contributory factors to be related to models of good practice, such as the approach developed under the EU-funded ATOMOS project (rather than models of failure such as Generic Failure Types), and thereby supports the assimilation of preventative measures.

The base factual data, concerning the time history, activities and actions immediately prior to the incident, is extracted from the reported source. In general, the authors have found this data to be in sufficient detail and completeness, professionally recorded and trustworthy.

A typical high level analysis for the grounding of the "Royal Majesty" [7] is shown in Annex C to illustrate the methodology used by the authors. Further analysis of this incident has been presented previously [8].

Where the report highlights something as being a cause, this is identified on the mind map in red. Contributory factors are identified in blue. Where there are questions outstanding from the reading of the report, these are identified. There are a number of instances where correct mitigation or preventative action had been taken. These are identified with a tick.

The approach taken to the incident analysis has the following characteristics:

- It assumes multiple causes;
- It takes an event tree approach, where successive 'barriers' to an incident have been breached, but does not make assumptions about the number of breaches required to bring about an incident or the temporal sequence of their construction or breaching;
- Although Johnson [9] warns of the dangers of classification errors, it was decided to attempt a standard structure for attributing causes. It is believed that attributing causes to enabling systems through the life cycle is likely to be less obviously misleading than the types of coding scheme described by Johnson.
- It is aimed at identifying potential preventative measures rather than in-depth analysis of causes. Although words such as 'shortfall' and 'error' are used, there is no attempt to assign blame. The interest is in understanding, but principally in corrective action at a systemic level.

5. IDENTIFICATION OF MITIGATION MEASURES

A key outcome of incident analysis is to support industry learning by identifying factors which would have mitigated the risks. To be effective the mitigation measures must address the most elemental causal factors and not be targeted at some intermediate level. This means that the analysis has to get right back to those basic initiators. This increases the analysis and reporting burden and potentially requires expertise in all parts of the maritime community. However, the alternative is to miss vital opportunities. Further analysis can identify, at the basic level, causal factors which can be dealt with, often without incurring a massive cost penalty or increasing complexity.

Moving to 'learning from incidents' increases the number of lessons that can be learned from an incident. By structuring material around the stakeholders, it is intended that the transfer into good practice can be encouraged.

It is important that mitigation measures do not make the system more brittle (see Annex B). It is, furthermore, important that mitigation measures have general validity as there is no purpose in simply closing a unique stable door or introducing a measure which might prove counterproductive when applied more widely to different situations.

Learning opportunities from incidents must be applied wisely to ensure that the marine industry is well-served.

6. EXPERIENCE FROM APPLICATION OF THE STRUCTURED SYSTEMS APPROACH

Two case studies are detailed in Annex D and Annex E. A third, summarised in Annex C has been reported previously [8]. In each case the basic factual information is taken directly, and only, from the official investigation report. These working illustrations need to be read in association with the referenced report to gain a full understanding of the incident.

7. CONCLUDING REMARKS

The need for incident analysis has been formally recognised, and its format codified. The next step, perhaps, is to improve the value of lessons extracted and their adoption by members of the maritime community.

The work by LR has indicated that a systems approach to reconstruction and analysis, combined with a simple compact presentation format, offers the potential to glean more information from an incident and to simplify the transfer to corrective or improvement action. The number of marine incidents that are thoroughly investigated is relatively small and it is important to use these "tales of what actually happens" to maximum effect. Since each is, essentially, a sample taken at random these represent an opportunity to dig beyond the immediate causes of the incident under investigation and the process described in this paper provides an effective way to achieve the desired aim.

8. ACKNOWLEDGEMENT

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10. AUTHORS' BIOGRAPHIES

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ANNEX A

SYSTEMS IN THE MARITIME COMMUNITY

The system elements/relevant systems have been identified in a number of ways e.g. Rasmussen [10] has government, regulators, company, management, staff, work. This and the Moray analysis [11] are based on approaches to analysing each system. The LR basis for identifying relevant systems was by 'systems of work' that affect the safety of operation. They are as follows.

Locus of shortfall	Relevant system(s)
Design and build time errors	Design office, shipyard, equipment manufacturer.
Regulatory shortfalls	Regulators e.g. IMO, Class, Flag, PSC
Operational shortfalls	Company
Near-term risk mitigation missed	Crew
Immediate build-up risks	Watch
Post-incident opportunities missed	Crew, Rescue service

The relevant systems have been variously portrayed as a hierarchy [10], a nested hierarchy [11], and as layered defences in depth [12]. These representations present some conceptual difficulties and are graphically difficult to use for portraying the trajectory of an incident. They are perhaps more appropriate to sectors that are less fragmented than the maritime sector, such as nuclear power generation. Fishbone diagrams may be more suitable but also bring with them some inappropriate conceptual background.

The dymamics of the interactions between regulatory system elements have been discussed [10, 13, 14] but are considered a second order issue here and not discussed further. The portrayal of such interactions would require a different format, such as an influence diagram.

ANNEX B

SYSTEMS, CAUSATION AND CREATING SAFETY

Incidents have large numbers of 'causes'. Wagenaar [15] has shown *"The number of causes in the 100 accidents ranged from 7 to 58 with a median of 23. The median number of 12 gates per network indicates that* *the number of steps between the remotest causes and the final consequence was fairly large. Much bigger than even a very experienced chess player would consider in deciding about the next move.....The analysis of 100 accidents at sea has brought us to the conclusion that the acts which lead to an accident are part of a complex causal network that cannot be overseen by the actors. Errors do not look like errors at the time they are perpetrated, and the accidents that are caused by them look impossible beforehand"*. The number of causes identified was considered to be conservative because of the source data used.

Complex systems are not inherently safe (Cook [2]); people continually create safe systems by local adaptations. With hindsight, some of these adaptations can look like errors.

Taking a limited view of 'cause' may do something to prevent a re-occurrence of the identical incident but may do little to prevent the next one. Even this may be optimistic. *"Views of 'cause' limit the effectiveness of defenses against future events. Post-accident remedies for "human error" are usually predicated on obstructing activities that can "cause" accidents. These end-of-the-chain measures do little to reduce the likelihood of further accidents. In fact that likelihood of an identical accident is already extraordinarily low because the pattern of latent failures changes constantly. Instead of increasing safety, post-accident remedies usually increase the coupling and complexity of the system. This increases the potential number of latent failures and also makes the detection and blocking of accident trajectories more difficult."* (Cook [2])

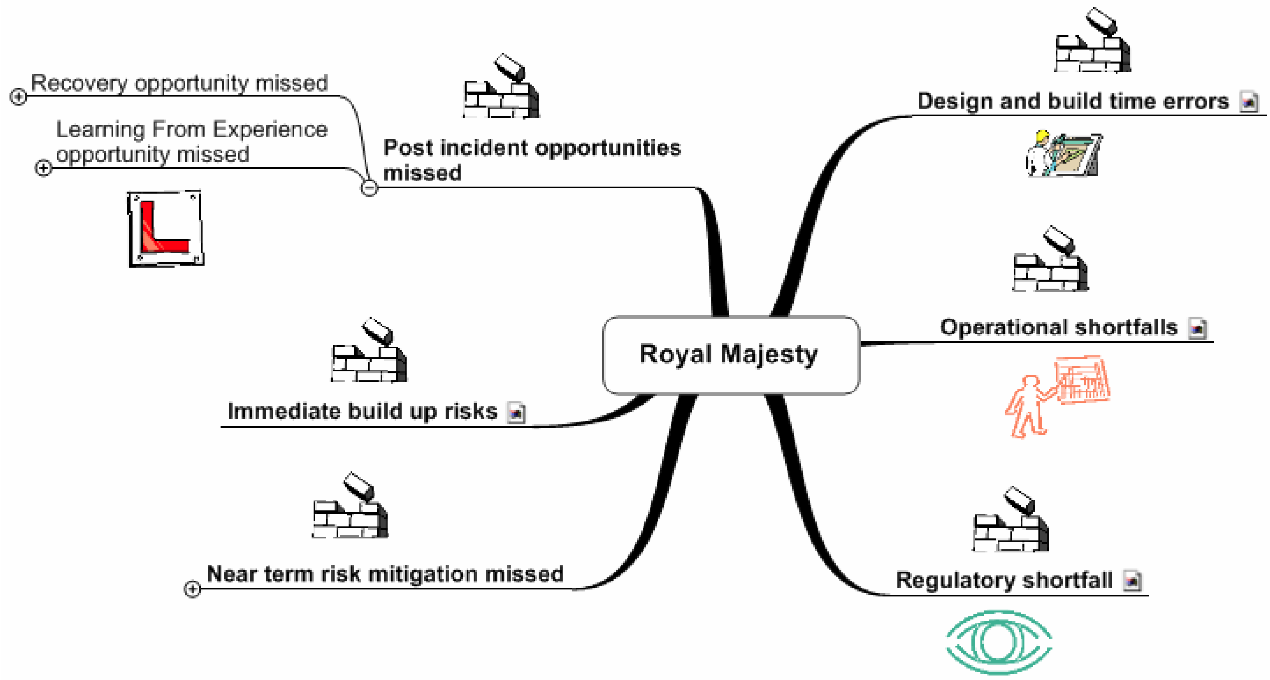
The mechanistic analysis of the coupling shaft in Figure 1 is appropriate; such a process could conceivably be described by equations. However, such an analysis is not appropriate to the bridge, the design office or a fitting shop. Weinberg [16] points out the limits of mechanistic analysis and statistical analysis and the use of system to fill "the yawning gap in the middle". The idea of strict causality and the treatment of counterfactuals then changes.

The authors propose that active failures (and hence incidents) occur when the demands of earlier shortfalls exceed the resources available to create safety; "an accident waiting to happen" is a fair summary of the build up to many incidents. The systems approach gives philosophical support to 'learning from incidents'. The specific causal path attributed to an incident assumes less importance, and the shortfalls identified that were not deemed directly causal become worthy of consideration.

ANNEX C

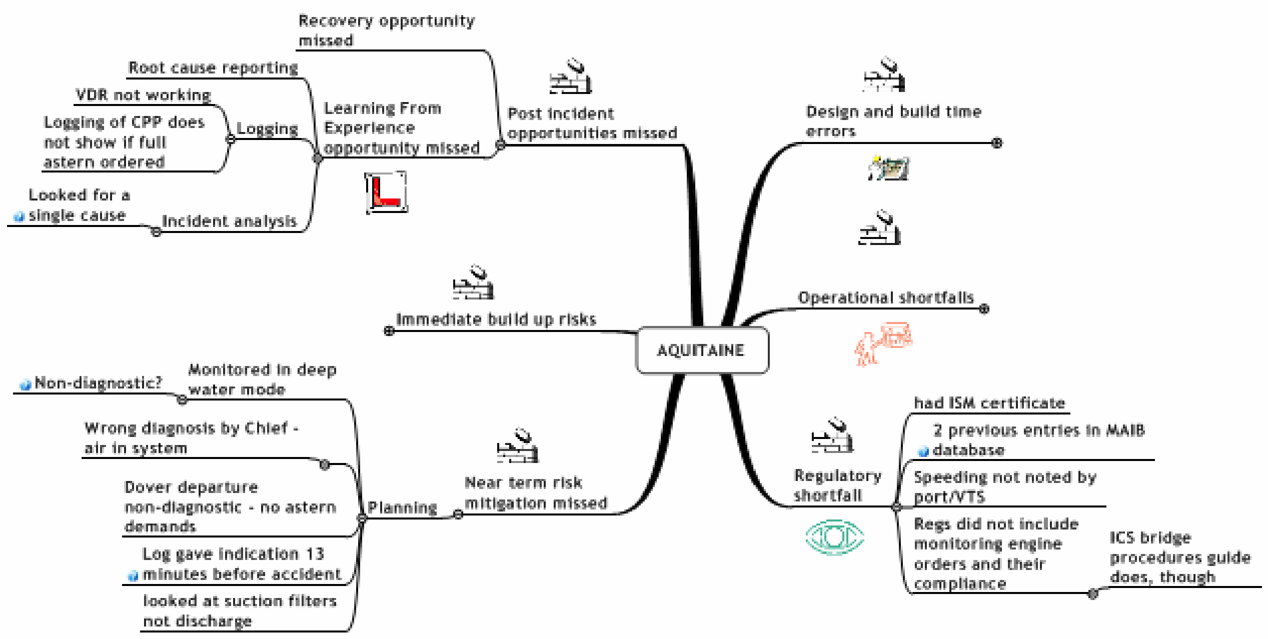
ILLUSTRATION OF THE PRESENTATION FORMAT

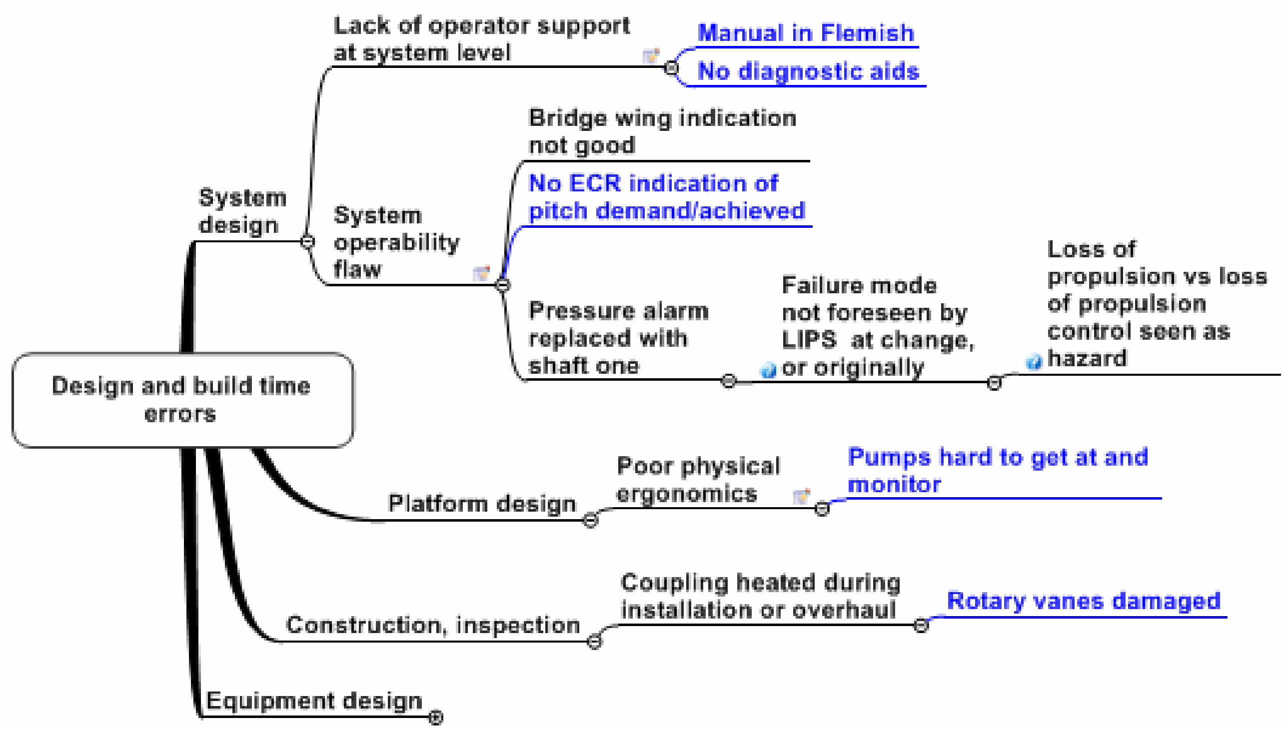
High level analysis of the incident involving the grounding of the passenger ship "Royal Majesty" [7]

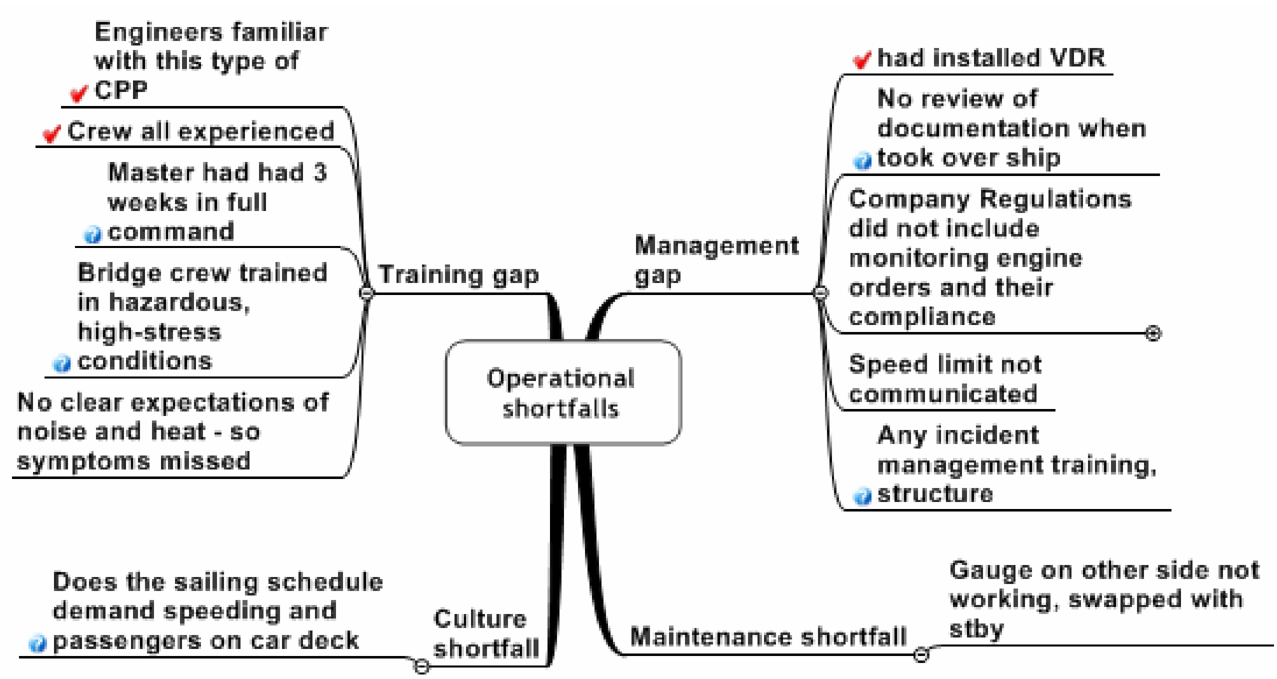


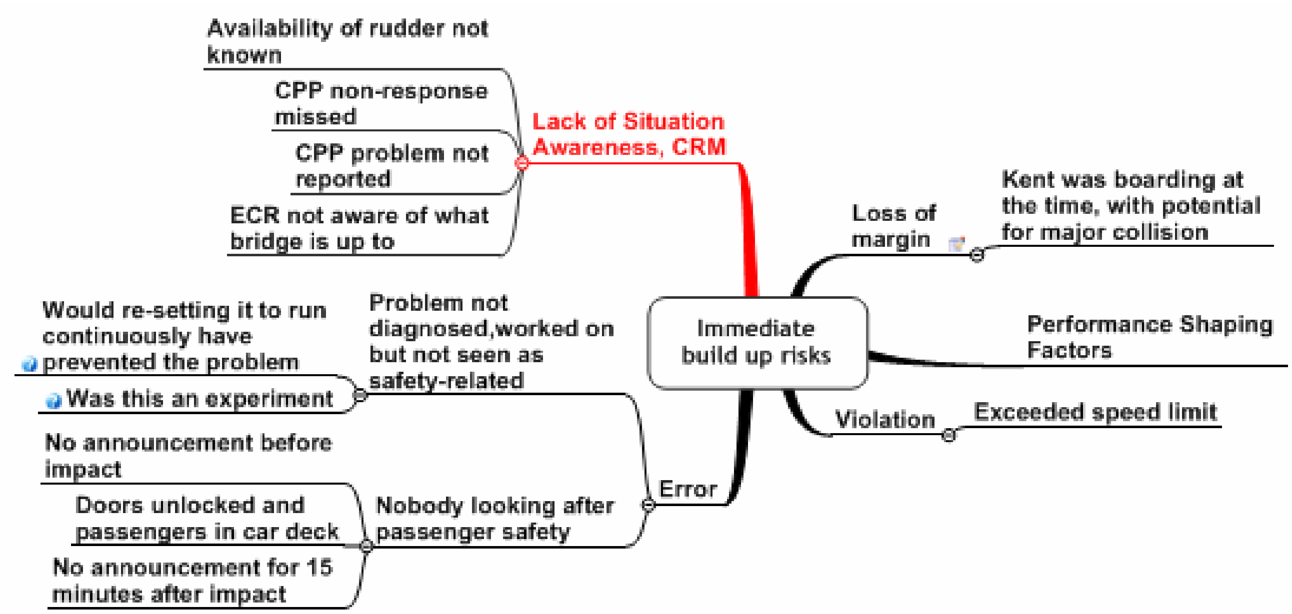
ANNEX D

ASSESSMENT OF THE INCIDENT INVOLVING THE CONTACT BETWEEN "P&OSL AQUITAINE" AND THE BERTH AT CALAIS [17]






Engineers familiar with this type of CPP
Crew all experienced
Master had had 3 weeks in full command
Bridge crew trained in hazardous, high-stress conditions
No clear expectations of noise and heat - so symptoms missed
Training gap
Management gap
had installed VDR
No review of documentation when took over ship
Company Regulations did not include monitoring engine orders and their compliance
Speed limit not communicated
Any incident management training, structure
Operational shortfalls
Does the sailing schedule demand speeding and passengers on car deck
Culture shortfall
Maintenance shortfall
Gauge on other side not working, swapped with stby


Availability of rudder not known
CPP non-response missed
CPP problem not reported
ECR not aware of what bridge is up to
Lack of Situation Awareness, CRM
Kent was boarding at the time, with potential for major collision
Loss of margin
Immediate build up risks
Performance Shaping Factors
Violation
Exceeded speed limit
Would re-setting it to run continuously have prevented the problem
Was this an experiment
Problem not diagnosed,worked on but not seen as safety-related
No announcement before impact
Doors unlocked and passengers in car deck
No announcement for 15 minutes after impact
Nobody looking after passenger safety
Error

ANNEX E

ASSESSMENT OF THE INCIDENT INVOLVING THE LOSS OF "JAMBO" [18]