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Using occurrence data to map the elements of a risk model

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A Risk Model (RM) is a powerful tool to understand major accident categories and to provide information about the consequences of human actions and influences. A maritime Collision in Congested Waters RM model developed as part of SAFEMODE and provides a quantified approach that allows human actions to be understood in relation to an accident – describing both positive and negative contributions to an event. This paper presents the validation processes for the RM development and includes two phases: Part 1-Testing of the RM using real-world incidents to confirm the model can consistently describe the events in an incident. Part 2 provides feedback from stakeholders on the RM to improve the robustness and utility of the model and identify its applications to their activities. The results of the validation activities indicate that the RM has domain utility. However, directed applications, whether these be a post-accident forensics assessment, training or foresight visioning of the introduction of new technologies and operational procedures, requires further examination and exploitation.

Keywords: safety, risk models, human shaping factors, maritime, aviation

1. Introduction

Currently there are conceptual and practical limitations on the application of human factors (HF) frameworks for the design of transportation systems and operations. Technology-focused designers (and other system actors) are not always able to understand or predict the potential impact of their designs on human performance and are not usually aware of the potential for identifying and mitigating HF problems to improve the chances of recovery from system failures and adverse events.

The EU funded SAFEMODE project provided a platform for stakeholders from the maritime domain to pull knowledge and best practices from the aviation sector with respect to the identification and mediation of accident risk. The maritime industry has a less matured culture in risk assessment compared to other safety critical domains. This has created challenges for the industry, *inter alia*, a lack of standardization of the processes for accident investigations, reporting and, more importantly, acknowledging a scarcity of the number of incident reports (i.e., near misses) that often provide the much-needed insight into error aetiologies and the application of risk models (RM) to study these issues.

Risk modelling can be used in the design and control of operations. The emergence of digitalization and automation has become ubiquitous in the undertaking of navigation practices and has created, paradoxically, safety-related problems (Bainbridge, 1983), due to continuous changes in how *work is done*. It would be advantageous for the industry to adopt a risk-based methodological framework that demonstrates its utility, usability, adaptability, and robustness to generate an acceptance within the industry. This work addresses the following questions: (1) Can a risk modelling framework applied in other safety critical domains, such as aviation, be tailored to serve the needs of a maritime socio-technical system and (2) would such a RM satisfy the needs and capacities of the maritime socio-technical system?

The paper describes the validation process for a RM to assess collision risk in congested waterways. The validation activities were divided into two parts: (1) Mapping of incident data using the developed RM. (2) Analysis by subject matter experts (SMEs) (outside of the project consortium) regarding the model barriers. A face validity approach was applied to study the problem. This method considers how suitable the content of the components of a model seems to be and is based on a subjective assessment by SMEs from industry and academic stakeholder groups.

2. Methods

Initial work by the project was to develop and utilize a methodology to develop a RM. The key elements of the RM are the backbone, contributors, and influence layer (composed of shaping factors that contribute to the occurrence of the event). The backbone is the main part of the structure of the risk models and is mainly composed of a set of precursors (safety events or hazards) and a set of barriers (defences). It is the first RM element to be built and it provides structure in the development of the rest of the model at the level of contributors through to the corresponding occurrences. It is a ‘simplified’ view of the model that can be very helpful when using the model, for example, to perform an initial assessment of a change in one or several elements of the system contributing to a specific risk. The backbone has different branches where contributors, or base events, describe conditions or attributes that determine or modify a precursor, which are then combined in an escalating safety condition. These base events can occur independently from other base events or may need to occur in conjunction with them. These conditions can be described with logic “OR” or “AND” gates describing the interdependence of base events at the same severity level in the model. Each of the base events in the model need to be clearly defined with correct terminology. The appropriate influencing factors relevant for the base events are reasoned out separately while mapping the incident reports.

Once developed, a two-part RM validation approach was undertaken, specifically for a RM scrutinising a major maritime accident category - Collision in Congested Waters (CCW). Part 1 of the validation process addresses the proof-of-concept activities, whether the model can capture information in real safety occurrences as intended. This face-validity approach involved analysing several real-world incidents using the proposed RM. The RM information should be able to describe how base events are defined to capture the human actions and errors as a contributing factor leading to an accident. This can be co correlated and identified in depth with the help of influencing factors developed in the RM taxonomy. Part 2 addressed the applicability of the model. SMEs for various stakeholder groups (not involved in the RM development) were requested to undertake an online survey and give their opinion on the design of the model and the intended uses. There was a total number of 39 respondents, including 17 complete data sets. Following the online survey, a workshop attended by another group of 18 SMEs was held to present the online survey results. This workshop was used to ratify that initial model and the survey results would corroborate that the model was valid.

An overview of the development process is shown in Figure 1. These steps involved creating the structure and taxonomy (Stroeve et al, 2022) of the different elements of the RM. Once the RM was developed, its validation (step 6 in Figure 1) is needed to assure that that the model is suitable for application, including the task of quantification (step 5).

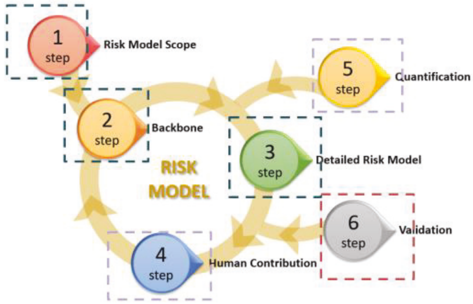

Fig. 1. RM development and validation phases.

3. Results and Discussion

3.1. Mapping of Incident Data: Validation Part 1

The main objective in this validation activity was to establish if the RM, in terms of structure, concept, terminology, and flexibility, satisfied the goals for the proof of concept. The RM was assessed to confirm that it could accommodate different incidents and accidents of a specific type and capture as much of the human contributions and subsequent failure of safety barriers leading to an incident. This included the following steps:

(i) Review of the incident report
(ii) Understand what is written and how it was conducted
(iii) Evaluate and modify the taxonomy commonly employed in maritime accident investigations
(iv) Allocate contributing factors and influence layers to the incident
(v) Update the model

The validation of the RM mainly focused on the following aspects: (i) Backbone elements and structure-correctness and completeness, (ii) The human factors contributing to an accident can be captured via base events and further categorized into different sections in RM taxonomy. Based on ontological considerations, the concepts used in the RM and design of the base events were related to industry practices and included terminology employed within the maritime domain. This helped identify key human factor contributors during the review of accident reports that could ¨trigger¨ the faults that activate the gates in the RM structure that resulted in escalation up towards the backbone layer.

RMs are intended to capture all possible real-world incidents but it was anticipated that some incidents could not be directly mapped onto the original RM, as the reports developed by different maritime investigators and stakeholders is not standardised and cannot capture all the relevant details involving in the accident. The "deviations" from the RM capturing the proper incident details were identified. Such deviations included inappropriate "AND" and "OR" gates, confusing terminologies, redundant or nonrelevant base events that did not contribute to the quality of the RM. Part 1 of the validation inspected these aspects of the RM in different ways. The context of the RM is dependent on the domain and thus Part 1 validation activities involved experts from that domain.

Review of the RM model was mapped with 40 occurrence reports sourced from various national maritime accident investigation databases. Most reports typically provide a detailed description of the causal factors and root causes of accidents, although variations in detail and analysis depth in reporting structures were observed amongst national investigation agencies. The analysis of accident investigation reports prepared by national administrations focused on the identification of failures of risk control measures or human actions that led to the accident. The process of mapping occurrence reports to the RM was aided by a template to standardize the type of data to gather.

Using the RM, the base events relating to human performance influencing factors were captured and allocation of performance shaping factors was performed for a particular captured base event. Therefore, the results obtained from the analysis of these accidents present information related only to the failures of barriers. Near-miss reports have not been analysed due to the limited access to this type of report and the lack of good quality data to facilitate the analysis; this information is rich and, when available, and should be considered in future risk modelling activities.

The number of barrier failures identified from the accident reports presented in Table 1. The overview of the developed RM at the backbone level and the elements that compose the backbone such as barriers, induced events, circumstantial factors, and the ranking of the failure contributors are considered.

Table 1. Collision in congested water top contributors to failure.

Barrier Failure Description	Occurrences (#)
No Communication with Master	11
Late execution by the Master and/or OOW for emergency manoeuvring	10
OOW does not execute COLREGS	8
No or late sound warning	8
No execution by the Master and/or OOW for emergency manoeuvring	6
OOW fails to monitor targets	5
OOW's inadequate watchkeeping due to sole look-out	5
No/Late visual warning	5
No/Late communication from OOW	5
OOW's inadequate watch keeping due to solo lookout	5
External observation not performed	5
No execution for a safe passage by OOW	5

3.2 Deviation Results

The results from the deviation reports collected from various maritime partners from different case analyses were mostly terminology changes in the base events that could be made generic and better suited for capturing the human-related contributing and influencing factors. The terminology changes were also made in the backbone structure and barriers. The other deviations identified were inappropriate "AND" and "OR" gates used to complement the links to the contributors failing or success of the barriers and requirement for additional base events.

While the SAFEMODE approach considered developing a generic taxonomy to classify the safety elements important to capture within a RM, perhaps an ontological lens is necessary to address the relationship between training, experience and operations distinctive of various safety critical systems. This may be an important consideration to promote adoption within the maritime domain to such a risk assessment paradigm. Optimistically, the SMEs engaged in Part 1 of the validation exercise seemed not to think that these taxonomy differences were insurmountable through more model refinement activities.

3.3. Stakeholder Survey of External Experts and Analysis of the Feedback: Validation Part 2

External maritime domain expert reviews were completed using a targeted survey. In addition to the expert survey, a workshop with stakeholders external to the research consortium, was organised to present the results of the survey and gain feedback from the participants, as well as to discuss the previous validation activities. These external experts consisted of safety specialists, human factors and ergonomics consultants, safety and risk superintendents, Master mariners/Captains, simulator training professionals, as well as researchers, professors, and postdoctoral students from academia that had not been involved previously in the RM development. This provided the opportunity to obtain feedback from the industry point of view and RM applications in their business practices.

3.3.1 Results from the Online Survey

The survey provided information about the recording of the critical events within their organisations where more than half of the participants responded as ¨yes¨ for the question "*Does your organization record incidents (near collisions) or accidents (collisions with property damage)?*". Half of the respondents stated that these collected incident reports were self-reported, and the rest were mandated by industry and government requirements. The participants also reported that their organisations request and review the data collected by external parties for internal purposes. The predominant use of the data collected by the organisations was to improve their training activities and their operations. Other uses were feedback to relevant groups directly involved in the event and dedicated analysis to design new technology.

The participants provided their opinions for the question "*What could be your first application of a SAFEMODE RM*?". These results can be found in Table 2.

Table 2. Survey representation for application of SAFEMODE Risk Model

Type of Application	Respondents (%)
Identifying Trends and Patterns in the Risk Model	30
Quantifying the Separate Factors in the Risk Model	14
Understanding the Incident and its Key Events based on the Risk Model	34
Focusing on Specific Elements of the model (e.g., use of navigation or communication equipment)	11
Other	11

For the question "*For projects in your organization, at which stage would you anticipate using this RM and for which purpose?*". These results can be found in Table 3.

Of the fault tree structure that identified "barriers" or safety measures that will prevent events from escalating, 73% of the participants mentioned that the structure of the RM was too rigid, suggesting that identifying base events are not flexible and the analyst might be forced to choose already defined base events within the RM. The base events designed to capture the human factors within an incident/accident are limited in scope and may not be consistently coded across similar incidents. This can make it difficult to precisely quantify specific base events using the RM. However, other comments suggested that it is necessary to assess the risk quantitatively and the user can become more familiar with the RM over time. In quantifying the elements of failure (or success) and the data obtained using the RM, 34% of the participants voted mainly for the option "understanding the incident, its key events and identifying the trends & patterns using the RM".

Participants provided input on how the RM should be implemented in various applications. Some of these were: "the developed RM may be used within the company for training purposes for marine officers to highlight accidents and escalation of accident risk". With the help of the RM the operating procedures can be optimized. According to the participants, RM might potentially be utilized by Health, Safety, Security, Environment and Quality departments for internal safety review and assessments. Acknowledging these application opportunities, the SMEs interviewed did not consider fully the foresight applications of such models – an approach and opportunity to ¨engineer out¨ potential black swan events using a bottom-up, human-centric perspective of control of operations. The RM can be used to support the design of new concepts and/or incident analysis, particularly if it is done within a simulator-based experimental approach.

In response to the inquiry about the feasibility of adopting RM to harmonize industry incident reporting procedures, 92% of the participants were in favour of further investigating. The remaining participants mentioned that it depends on the person who is supposed to do the analysis and it must not be too complex for small organisations.

Concerning limitations of the RM the workshop attendees provided the opinion that they were created using a systematic taxonomy based on accident reports and, when considering all scenarios, the RM may not result in capturing all the barriers for success mentioned in near-miss and incident reports. Furthermore, if the RM is used at the time of writing the incident report, the writer may be limited to just picking from the alternatives provided by the model, restricting the identification of new risks and hazards.

Table 3. Survey representation for use of Risk Model for quantification.

Type of Application	Respondents (%)
Support of Incident Investigation	29
Identify Main Contributors to Risks in Operations	25
Perform and Initial Impact Assessment of Bridge Operational Procedures	23
Support the Design of Equipment and Operational Environment Considering the Human Contribution Risk	23

4. Conclusions

¨Can a risk modelling framework applied in other safety critical domains, such as aviation, be tailored to serve the needs of a maritime socio-technical system?¨

The RM demonstrates sufficient face validity for continued development, with the proviso that development of this model and others in the future needs to be simplified and made more userfriendly. While a certain level of cross-disciplinarity is needed to practically utilise these models, the application of the process needs to be more general to promote common ground and utilisation within the maritime safety system.

Unlike other industries (*e.g.,* nuclear and aviation), shipping lacks the regulatory direction that promotes a performance (goal) based approach to address risk mitigation. The industry tends to use these types of RMs in a forensic manner, rather than as a foresight tool. Certain elements of the industry may be slow to adopt until a business case for safety is created and is supported by technology developers, training institutions, regulatory authorities and a more shared safety culture within the domain.

"*Would such a RM satisfy the needs and capacities of the maritime socio-technical system?*"

The primary value of such a RM is to prevent incidents or accidents from arising during operations. Given the emerging challenges of new equipment design and system integration (*e.g.,* levels of automation) and defining the concept of operations, it seems that this approach does have sufficient level of validity to make a positive impact in the shipping industry. However, it will be important for all maritime stakeholders to mature the socially constructed capacities (generative, absorptive, and disseminative) to promote a constructivist lens to knowledge mobilisation to address safety within complex maritime socio-technical systems (Parent et al. 2007).

The SAFEMODE risk models can:

- be translated into training activities to improve operations by identifying the different contributing factors that lead to the accident.
- identify operational barriers and safeguards which in turn will optimize standard operating procedures.
- inform the risk assessment of new designs and modification of the existing ones.
- help in accident investigations by identifying key HF that contribute to the barriers' failure and the overall risk.

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