SEMOMAP

SEquential MOdel of the Maritime Accident Process

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Abstract: An important issue of accident investigations is to find out how barriers installed in technical systems failed and enabled interactions of active failures and latent conditions to develop into the accident. For this purpose models and data taxonomies have been developed to facilitate the reactive risk assessment process after an accident. This paper is intended to focus on maritime accident investigation and the specific models and approaches used for the above-mentioned purposes. In line with current international research activities a sequential model of the maritime accident process (SEMOMAP) and a related data taxonomy will be introduced. Furthermore, results of a first trial application will be reported.

Key words: maritime accident analysis, maritime accident modelling, maritime accident data taxonomy

1. INTRODUCTION

Accident investigations are an important part of the safety standard definition process. They reveal existing safety gaps and offer the opportunity to review existing safety standards or to adopt new regulations. Safety gaps are often linked to failing barriers in human-machine interaction. For this reason many accident investigation and risk assessment approaches concentrate on barrier or defence analysis (e.g. Reason, 1990, with his *Swiss cheese analogy*). Safety barriers are integrated in each technical system. It is usually in the design phase, when decisions are made, that consideration should be given as to which barriers should be integrated and how they should function. An important question is how the evaluation of effectiveness of the barriers can be made in each system. The sad truth is that barriers are analyzed mostly in the follow-up process to an accident,

since day-to-day routine working data are not stored in industries other than the nuclear industry and incident reporting schemes have not yet been successful in many industries (e.g. *IMISS* – Ferguson, 1999). For the purpose of the more specific argument in this paper shipping was chosen as a transportation mode, because it is generally considered risky and therefore needs further consideration with regard to the improvement of safety standards. In the shipping industry the reactive approach to accidents is still the most significant driving force in ship safety (Psaraftis, 2002).

The International Maritime Organisation (IMO), as the specialised United Nations (UN) agency for maritime affairs, has always considered the improvement of ship safety through accident investigation as one of the most important objectives of the organization. In addition to the IMO, further approaches by international and national bodies and institutions were made in order to enhance maritime accident investigation. Apart from pure legal considerations, one of the main issues has always been how maritime accident investigation can be scientifically supported. In this regard some methods have been developed to be used for maritime accidents. Some of them have been adapted from other transportation disciplines, such as aviation (e.g. *SHEL* – Hawkins, 1987), whereas others were solely developed for shipping (e.g. *SAFIR* of the Norwegian company BASS). As far as human-machine interaction is concerned general models, e.g. Reason's (1990) *Hybrid model*, have been applied very often.

One point for discussion is certainly the question of whether accident investigations should focus on the characteristics of the specific industry branch or transportation mode involved. As far as the understanding of human-machine interaction is involved, general approaches are helpful. However, if the improvement of a certain system is the main focus of the investigation a high degree of abstraction might not always be desirable. This philosophy could have been the reason for the European Commission (EC) to stimulate research (such as *BERTRANC*, *CASMET* or *THEMES*) on specific maritime accident and risk assessment methods. In line with the findings and objectives of the above mentioned research activities *SEMOMAP* – a *SEquential MODEL of the Maritime Accident Process* was developed. This paper is intended to introduce *SEMOMAP* and a related data taxonomy developed for *SEMOMAP*. Furthermore, first applications will be reported.

2. CURRENT MODELS AND APPROACHES USED FOR MARITIME CASUALTY ANALYSES

Accident causation models were first introduced when H.W. Heinrich (1931) started to look at accidents in the early 1930s. Overviews about the development of models and taxonomies and current approaches to accident and human reliability analysis can be found in Kirwan (1994), Reason (1990) and Hollnagel (1998). Johnson's (2003) recent book contributes to this topic as well.

The IMO makes specific reference to Reason's (1990) *Hybrid model* and *GEMS*, as well as to Hawkins' (1987) *SHEL* model in its documents when human failure is targeted during maritime accident investigation. Whereas *SHEL* describes the different types of interaction in human-machine interaction systems, the Hybrid Model is looking at accidents primarily from an organizational point of view. In addition, *GEMS* describes types of behaviour and related errors. All models can be applied to any accidents, no matter which transportation mode is involved.

Apart from the IMO, the EC has supported intensive research projects on specific maritime accident investigation and risk assessment approaches. The most prominent projects/actions are BERTRANC, CASMET and THEMES. In aviation, many specific models i.e. on decision-making processes in the cockpit are available, yet only a few specific maritime accident causation models have been developed over the years. The models/taxonomies that are discussed in the reports of the projects above are among others:

- *CASMET* approach (CASMET);
- *TRIPOD* (Reason, 1997);
- *Loss causation model* (DNV);
- *Systematic learning from incidents* (Kristiansen, 1995).

In addition the following databases were consulted:

- *DAMA* (Norway);
- *M-SCAT* (Norway, DNV);
- *SYNERGY* (Norway);
- *SAFIR* (Norway);
- *MINMOD* (USA).

The above-mentioned approaches/models/taxonomies have been successfully used in the maritime industry for years. Most of them are based on accident causation models. *TRIPOD*, the *Loss causation model*, *M-SCAT* and *SYNERGY* look on the accident primarily from the organisational point of view, identifying failed defences prior to an accident. The *CASMET*

approach is sequential in its data taxonomy. The model used in the approach is not an accident causation model but rather a human factors interaction model. Kristiansen's *Systematic learning from incidents* and the taxonomies of the remaining databases *SAFIR*, *MINMOD* and *DAMA* are not based on a specific accident causation models.

One question that might arise at this point is why it is necessary to focus on specific systems or transportation modes, rather than applying general models and taxonomies. One argument for the focused approach an accident investigation is certainly that the data resulting from these investigations are further used for detailed risk assessment purposes. In order to support detailed risk assessment solid data about the accident process as such are required, including human performance data. None of the above approaches collects information about the emergency management process. This type of data is important, too, specifically since some defences (e.g. structural fire protection on ships) start to function only after the accident was initiated. This was the motivation to develop *SEMOMAP*, a model that is more focused on the accident process and how defences function during this process rather than the context in which the accident process occurs. However, as many scholars (e.g. Hollnagel, 1998) point out, a process cannot be evaluated without taking the context in which it occurs into consideration. This is why data that contributes to the assessment of the impact of performance shaping factors (PSF) have been included into the *SEMOMAP* taxonomy too. The following paragraphs introduce *SEMOMAP* and its taxonomy in more detail.

3. SEMOMAP

SEMOMAP (Figure 1) focuses on the human operator during the maritime accident process, while specifically targeting the emergency management process. The model considers features of the approaches mentioned in the previous paragraph. The accident process has been subdivided in *SAFIR* (latent, initialising, escalating, critical phase) and *CASMET* (a step model is used for the coding of the data). The defence principle, which is used in *TRIPOD* can be found in an applied way in *SEMOMAP*. The approach of *SEMOMAP*, however, is slightly different from the above-mentioned models. *SEMOMAP* is based on the Model of Human Recovery and Human Error Management (van der Schaaf, 1992) and the Model of the Navigation Process in an Emergency Situation (Modell des Schiffsführungsprozesses in einer Notsituation – Hahne et al., 2001). It is much more focused on the question of why some accidents develop into total

losses and why others can be successfully mitigated at a certain level of the accident process. In this respect, defences in the human-machine interaction have a vital role to play.

Figure 1. SEMOMAP – SEquential MODEL of the Maritime Accident Process (Source: Schröder, 2003)

SEMOMAP is a sequential model. In order to support the focus on the accident process as such, the impact of the human element context was not integrated. This was considered in the taxonomy, where information about influencing factors on human performance were collected. The idea of *SEMOMAP* is once again to focus on the question why in some systems defences fail in a way that an accident resulting in a total loss, where as in other systems the accident process can be stopped at a certain point due to appropriate emergency response measures. *SEMOMAP* therefore subdivides the accident process into six stages/results (Schröder & Hahne, 2003):

- Dangerous situation;
- Beginning accident;
- Near miss;
- Accident;
- Mitigated loss;
- Total loss.

4. SEMOMAP DATA TAXONOMY

Keeping Hollnagel's (1998) Method, Classification, Model (MCM) framework in mind a data taxonomy has been developed for *SEMOMAP*. An attempt was made to reconcile and combine the input of the relevant IMO instruments (i.e., Code for the investigation of marine casualties and incidents – Res. A.849(20), Res. A.884(21)) and the input of *SEMOMAP*. Special emphasis was laid on the requirement that observations and interpretations should be separated (Hollnagel, 1998). The data collected through application of the taxonomy should be free of interpretation to a high degree. The application of the taxonomy should also lead to the indication of safety critical issues for further improvement. The *SEMOMAP* taxonomy is displayed in Figure 2. Data sections in the figure which are marked with “...” indicate that additional data are required to be entered in the particular section. This would mean, e.g., that “Additional data for the accident category” distinguishes between the following four accident categories:

1. Collision;
2. Grounding;
3. Inrush of water;
4. Fire.

The IMO (Res. A.884(21)) focuses on pollution discharged from ships in addition to the four categories included in *SEMOMAP*. When *SEMOMAP* was designed the emphasis was laid on serious accidents. This is why the

pollution as such was not included under accident categories into *SEMOMAP* to date.

Figure 2. Structure of the SEMOMAP taxonomy

The single *SEMOMAP* accident categories are also further detailed. The accident category “Fire”, as an example, is divided into the three sections, as Figure 3 demonstrates.

Figure 3. SYMOMAP data for the accident category “Fire” (Source: Schröder, 2003)

The subcategory fire fighting equipment deals with information that is not directly related to the accident. It is important information which is required, when, e.g., management influence on the safety policy of a company is the focus of an investigation. The taxonomy tries to follow the implications of Reason’s (1990) models with regard to decisions made/or lack of control at certain management levels resulting into favourable conditions for accidents and incidents. It may appear that the data collected in this category does not directly relate to *SEMOMAP*. This is partly true, as *SEMOMAP* concentrates on the accident process as such. However, accidents are the result of a causal chain, which is influenced by latent conditions that Reason (1990) focused up on in his models. As a result of these considerations, the *SEMOMAP* taxonomy was extended to data providing indications about the latent conditions in the system to be investigated, e.g. the status of the fire fighting equipment.

This also applies to HE related data and data describing the PSF. It is not only the more technically focused data in the taxonomy that are specifically detailed. The HE part is detailed, too, as Figure 4 demonstrates. In the HE part of the taxonomy especially the PSF cover a substantial part. There are 130 different data pieces collected in this section. The data structure for the PSF related data “HE – General situation on board” can be taken from Figure 5.

Figure 4. Overview about the HE related data in SYMOMAP (Source: Schröder, 2003)

Figure 5. Data from section “HE – General situation on board” (Source: Schröder, 2003)

4.1 Relation between SEMOMAP and its taxonomy

The objective of the taxonomy was to reconcile and combine the relevant IMO guidance and *SEMOMAP* impact with an approach that can be used by practitioners. The taxonomy, then had to be structured in a way that it can be used for checklists or databases, following the general principles of the IMO guidelines (Res. A.849(20) and Res. A.884(21)). The priority was to assemble all data that belong to a certain technical issue at one point in the taxonomy. This resulted into the problem that the *SEMOMAP* taxonomy cannot be directly linked to the model. Table 1 highlights this issue and demonstrates how the link between model and taxonomy functions.

Table 1. Link between SEMOMAP and the SEMOMAP taxonomy in the beginning accident phase for the accident category fire (Source: Schröder, 2003)

SEMOMAP	Related taxonomy section	
2. Beginning accident		
2.1 Failure detection	Fire detection and development	<ul style="list-style-type: none"> • Fire detection • Development
2.2 Situation assessment	HE - Beginning of the emergency situation and initial response	<ul style="list-style-type: none"> • Organization of emergency response teams
2.3 Initial response	Fire detection and development HE - Beginning of the emergency situation and initial response	<ul style="list-style-type: none"> • Initial fire fighting measures • Manning of the bridge • Coordination of initial measures • Initial measures • Involvement of pilots or VTS centres

5. OBJECTIVES OF THE SEMOMAP APPROACH

The model and the taxonomy can be used for accident analysis and safety defence analysis.

5.1 SEMOMAP and accident analysis

The *SEMOMAP* approach is not exclusively focused on the accident process. It can also be used by stakeholders in the maritime sectors that do not focus primarily on the accident process. In order to avoid different systems being used for accident investigations it would be impracticable to design a system in which only the accident process is displayed. Therefore accident causation was included as a factor in the *SEMOMAP* framework. Accident causation data enable the analysis of the whole accident process.

The data scheme allows for the quantitative risk assessment. For this purpose, investigators can contribute to the database through a complete set of information required for those purposes. The model can be used to link the data in a meaningful way. Current data gaps could be filled through expert judgement. In this respect Bayesian networks could be a possible application for the risk assessment with the *SEMOMAP* framework.

5.2 SEMOMAP and defence analysis

Another objective of the taxonomy is to support defence analysis. The philosophy applied to this approach is that *SEMOMAP* should support the observation and in-depth analysis of a system. This means there should be no interpretations from the system in the data acquired, and only observations should be entered. If there are safety gaps or weak barriers the data will point into that specific direction. This means that the interpretation has to start once the observations from the system are recorded into the data scheme. This may sound unsystematic, however, the model links the information in a meaningful way. A similar approach can be found in the *TRIPOD* methods (Reason, 1997), where data is collected, that has to be combined in a specific way in order to highlight areas of improvement. Although defences are integrated with a purpose into a system, it is not always demonstrated from the beginning how effective they function. In order to allow for an unbiased assessment of those defences, a taxonomy should be used that is not directly focused on the specific barrier, but rather on the overall performance of the system as such.

6. TRIAL APPLICATIONS OF THE SEMOMAP TAXONOMY

The *SEMOMAP* taxonomy was applied to investigation reports of 42 passenger vessel accidents which have occurred between 1979 and 1999 (Schröder, 2003). The findings were basically in line with studies in which a larger number of accident reports have been used (Hahne et al., 2001; Dreissig, 1996), as far as descriptive indicators about the general circumstances of maritime accidents are concerned (e.g. distribution of the accident risk over the day). In general, the results could be used to identify simple trends in the casualties involved. Detailed and comparative observations were often not possible due to missing data. The accident investigation reports were often detailed as far as technical data for the description of the physical accident process are concerned as Table 2 shows. Therefore the general level of reported technical data can be considered as

sufficient enough to reach conclusions. However in many particular sectors, specific information is missing. In addition to missing data about actions of the crew it was often not possible to gather data in the human performance area, as Table 3 shows.

Table 2. Missing data in the accident reports of the accident category "Fire/Explosion" (Source: Schröder & Zade, 2002)

Data category	Data sub-category	Percentage of missing data [%]
Fire detection and development	Fire source	0
	Fire detection	0
	Development	12
	Initial fire fighting measures	0
Fire fighting	Involved crew	100
	Accessibility to the fire	18
	Measures to fight the fire	12
	Further measures to fight the fire	70
	Times until commencing with actions	33
	Results	6
	Fire fighting equipment involved	27
Fire fighting equipment	Fire fighting equipment condition	45

Table 3. Missing data with regard to HE aspects in the investigated accident reports (Source: Schröder & Zade, 2002)

Data category	Data sub-category	Percentage of missing data [%]
HE – Beginning of the emergency situation and initial measures	Manning of the bridge	81
	Coordination of the initial measures	40
	Initial measures	43
	Organization of emergency response teams	77
	Involvement of pilots or VTS centres	93
HE – Emergency management	Manning of the bridge	96
	Coordination of emergency response actions	59
	Decision making	93
	Information gathering during the emergency	74
	Problems occurring during the emergency response actions	90
HE – Evacuation	Manning of the bridge	96
	Coordination of the evacuation	14
	Decision making	89
	Problems during evacuation	81

7. SUMMARY

In this paper *SEMOMAP* and its related taxonomy were introduced together with a trial application of the taxonomy to accident reports on passenger ships. Although the taxonomy could be applied and general trends

could be derived, the following gap has to be considered, which is the missing in-depth data concerning human operator performance. Reasons for this occurrence are related to insufficient information provided on HE background information in the accident reports investigated. The period in which the accident investigations took place covers a period of 20 years, starting from 1979. At this time HE was not considered a critical issue. Many approaches to deal with HE in shipping were more systematically addressed after the capsizing of the *Herald of Free Enterprise* in 1987. Since that time HE has been on the agenda of the IMO. Accident reports issued after this time usually reveal HE related data too a much more detailed extent. However, the US Coast Guard (1998) concluded:

“Human Factors: A high percentage of casualties are due to human error. However, quite frequently Investigating Officers fail to document the underlying reasons why the human error occurred. To provide a better understanding of these causes, a description of the human factors should be set forth in the facts.”

The National Transportation Safety Board of the USA (NTSB, 2002) came to a similar conclusion after assessing the contents of databases to be used for accident investigation follow-up processes. However, even if not all data are included in the accident reports they are very often recorded during the investigations and remain filed at the investigation bodies. This would probably be a more accurate source for in-depth studies on PSF and related data. The results of the *SEMOMAP* investigation seem therefore to be in line with the general situation of HE related data in the maritime field. The question is if the *SEMOMAP* framework can contribute to overcome the described difficulties.

7.1 Strength and weaknesses of the SEMOMAP framework

The strength of the *SEMOMAP* framework is certainly its focus on the overall accident process. New technical achievements in shipping, such as the Voyage Data Recorder (VDR) or the Automatic Identification System (AIS) will certainly provide maritime accident investigators with an increased amount of data that provides a deeper insight into the emergency management. This is where models like *SEMOMAP* are needed. The limitation of the framework is the taxonomy. The objective was primarily to facilitate the establishment of a database for maritime accidents. The data taxonomy has been developed with this objective in mind. As a consequence

the relation between the model and the taxonomy is not always consistent. The taxonomy is also quite large. This was a result of the consideration that specifically the data on the PSF has to be included. A difficulty could occur if the final result is now impracticable for handling during an accident investigations process and difficult to analyse in the follow-up process to an accident. Those questions can only be answered during the evaluation of the *SEMOMAP* framework.

7.2 Outlook

Another reason for the partially unsatisfactory data situation mentioned in this paper is that accident reports are generally not the most appropriate data source for studies like this. Accident reports reflect only on the most important findings and details of the investigation. It can be concluded that although sufficient data was gathered in order to derive first trends of maritime accident developments, a final validation of *SEMOMAP* is pending. Such an evaluation could be done in different ways. One way would be to invite other researchers to apply the *SEMOMAP* method on a particular accident scenario. Similar evaluations have been done in the past, e.g. within the THEMES project. The results of such evaluations could be considered as subjective. Another problem is that for such an evaluation a well-known and well-documented accident has to be chosen. This could also lead to a certain bias by researchers involved in the evaluation that are familiar with the details of the accident. Assumptions and hypotheses could lead to different outcomes of different evaluation teams. In the absence of other possibilities for the validation of such a system it seems that this is a practicable way.

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