Learning from Maritime Accidents by Applying Connectionism Assessment of Human Reliability

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Abstract

In this paper we present the first application of connectionism assessment of human reliability (CAHR) on maritime accident data. In conjunction with root cause analysis, represented by accident reports, the CAHR method investigates the work context from a holistic point of view.

To date, by IMO predominantly first generation methods, such as THERP, are recommended, for instance, to be applied in the context of the Formal Safety Assessment (FSA) process for rule development. It can be argued that validation of human reliability data used in these methods would be desirable, with respect to the maritime work operating environment. In the nuclear domain in Germany, the long term application of the CAHR method in the course of incident analysis made it possible to validate and gradually generate human reliability data.

This paper closes by defining the requirements that need to be fulfilled in order to apply the method in the maritime domain.

Keywords

CAHR method, connectionism assessment, accident analysis, validation and generation of human reliability data.

INTRODUCTION

By definition, the occurrence of accidents is undesirable, but in practice accidents do occur. Hence, the prime objective of safety analysis in practice must be to uncover the reasons that led to an accident in order to be able to derive adequate measures to prevent similar accidents from recurring on future occasions, Petroski (1992).

Root cause analysis is frequently employed in connection with accident investigation and documentation. One of the most frequently cited root causes in accident reports is the "Human Element" (e.g. Gray (1978)), and it is well established that the human performance depends on a number of influences, such as personal health, competence and situational awareness, social and cultural factors, legal influences and the technical condition of the ship (e.g., see (VDI 4006, Part 1) and (Moreton 2000)). However, only on few occasions in accident reports we find systematic investigations of the specific occupational circumstances the operating personnel had to deal with at the time of the accident.

In this paper we present the first application of connectionism assessment of human reliability (CAHR) to accident data from the maritime domain. As a perspective of a long term application of the CAHR method in conjunction with accident analysis, it is envisaged that the method eventually can be applied to validate and gradually generate human reliability data, for instance, as is used in first generation methods such as THERP (Swain and Guttmann 1983) and HEART (Williams 1988).

These methods are recommended by IMO to be used for the analysis of human reliability, for instance, in the context of the formal safety assessment process (MSC 83/INF.2). Notwithstanding, it can be argued that the human reliability data that is utilized by these methods originally was obtained in the nuclear and process industry domains, and that the validity of this data for the quite different maritime work environment has yet to be demonstrated (Kim *et al.* 2006) and (Lyons *et al.* 2004).

The CAHR method has already been applied successfully in the nuclear domain, to generate new and validate existing human reliability data (e.g. as used in THERP). Since 2010 the CAHR method has been acknowledged for use for that purpose by the GRS (Gesellschaft für Anlagen- und Reaktorsicherheit), a state-founded non-profit organisation focussing, amongst other fields, on the safety of nuclear facilities in Germany).

This paper closes by defining the requirements that need to be fulfilled in order to apply the method for that purpose in the maritime domain in a wider scale.

MARINE ACCIDENTS AND INFLUENCING FACTORS

The maritime industry is considered to be an error-inducing system due to the complexity and the enormous diversity of the interaction possibilities between the system components, which can lead to an accident (Perrow, 1999). Despite developments in technological equipment, enhanced "built-in" defenses and constant improvements in regulation issues, marine accidents continue to occur in rather high rates around the globe (EMSA Maritime

Accident Review, 2009). Most of these events do not lead to a total vessel loss or loss of human lives and as such do not raise extended public attention although they are mostly associated with high monetary costs. Perrow (1999) lists some of the reasons that may explain this somehow reduced resonance of events in the maritime industry as compared to aviation.

Perhaps the most prevailing cause for maritime accidents is associated with action on the level of behavior at the sharp end of the system labeled as human error. The contribution of the human element has been internationally considered as the main causing factor for the majority of the incidents and accidents investigated by responsible authorities in the maritime context (Hetherington et al., 2006). However, attributing the main responsibility solely to the human element under the label of human error can be prone to bias and hence misleading in respect to the actual reasons that lead to the accident, impeding the possibility to determine sustainable improving measures (Dekker, 2006; Wallace & Ross, 2006).

The description of human action as erratic often occurs from a locally and timely remote point of view, within a rather predefined interpretation framework, and without (or rather with a different set of) constraints for the persons involved. In order to be able to understand human actions in the context of such a remote analysis process, safety analysts must determine the means that will allow for comprehending the event-proximal reasons that lead to these actions. In other words we have to find applicable tools and methods that will be able to explain the reasons that made action seem plausible and adequate at the specific time and in the specific situation when the event happened (Sträter & Bubb, 2003; Woods et al., 2010).

In order to evaluate the cognitive behaviour of the human operators in a valid way within a complex, high-risk system one needs to take into consideration all the contributing factors that may influence system performance. These PSFs (Performance Shaping Factors) in the context of the maritime industry include all aspects of work in a specific situation: the available technology, person-related aspects, organizational and working conditions as well as weather and environmental conditions and other traffic actors involved (vessels and authorities) must be be adequately captured and analysed in order to gain a system-tailored and valid picture of the situations under discussion (Sträter, 2005; Hetherington et al., 2006). Capturing the relevant PSFs that influenced cognitive behaviour may pose the only possible way to provide for an unbiased representation of the cognitive systems, which determined the course of events. At the same time such an approach may enable stakeholders assigned with system safety to draw conclusions and to define lessons-learned with a generic value, forming a knowledge and information base for the purpose of optimizing future working processes and formulating control options for system and human reliability in the maritime industry.

SUMMARY OF THE CAHR-METHOD

The CAHR („Connectionism Assessment of Human Reliability“) method is a knowledge-based tool for analysis of the work context in observed incidents and accidents from a holistic point of view, Straeter (2005). Core elements of the analysis are the (sets of) “events” that contributed to the incident or accident. These include:

- technical events, i.e. operational procedures or trouble taken place without action of –or caused by– the individual,
- human factor relevant events, i.e. operational routine for trouble during which the individual successfully intervenes in incidents in some way, and
- human factor events, i.e. trouble where a human-machine system (HMS) is the originator or where an HMS system performed a fault intervention in an already faulty technical system.

The method is based on a “connectionism” analysis algorithm[1]. The key idea is the assumption that human performance is influenced by the interaction of a set of conditions and factors, rather than by individual factors that can be investigated in isolation. The philosophy of the method includes:

1. In the focus of the analysis is the complete working system, not just the human being. It is not an issue of the analysis to put blame on human operators.
2. “Errors” performed by the human result from a multitude of interactions of situative and causal factors in the work context.
3. The method provides a firm analysis structure but does not prescribe a fix taxonomy (open method). Hence, it is applicable to any type of incident and technical domain.
4. There is a clear distinction between observable behaviour and error classification (occurrence oriented classification) and the assignment of causes (cause-oriented classification).

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[1] The term originates from the topic of modelling of human cognition in the field of artificial intelligence.

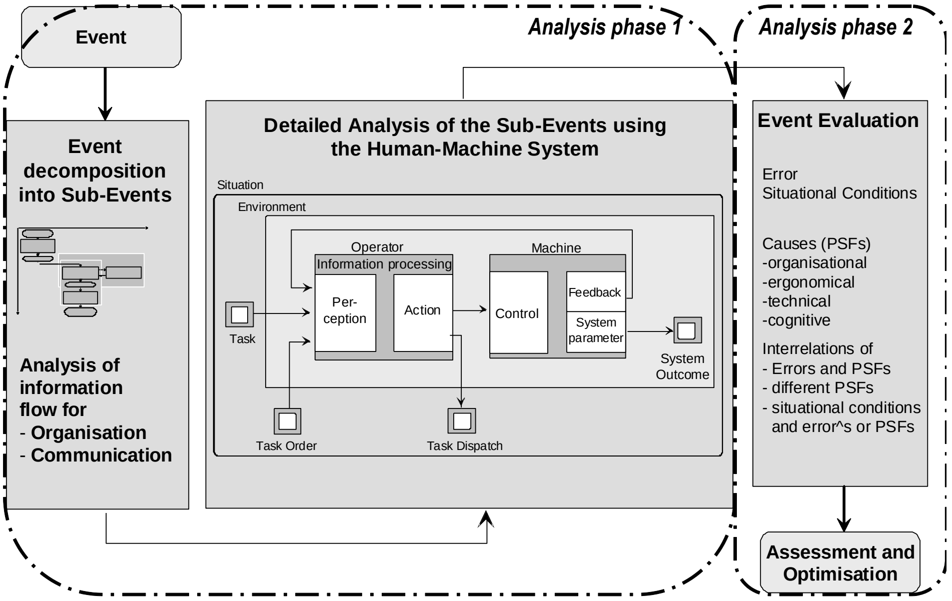

Figure 1. The Human-Machine System as Generic Element in the Acquisition of Human Actions (Straeter 2000)

The CAHR method originates from the nuclear domain. In that domain, by the analysis of 232 incidents, which were recorded in control rooms of German nuclear power plants, an initial knowledge base was created. This knowledge base is continuously expanded by adding further incidents, including events originating from other industries, such as air traffic control. Further details on the method are published in (Straeter 2000).

APPLICATION OF THE CAHR METHOD IN THE MARITIME DOMAIN

This publication documents the first application of the CAHR method in the maritime domain. In the current stage this work is seen as a proof of concept, to investigate the feasibility of the method for the purpose of generating and validating human reliability data for the maritime domain.

Data source

In this work a set of 21 reports was analysed, which were published by the German Federal Bureau of Maritime Casualty Investigation (BSU). Criteria for the selection of reports were collisions between merchant vessels during the period 2002 to 2009. For this work only reports were selected on accidents involving at least one container vessel (Table 1)[2]. Focus was put on navigational tasks of bridge crew, as well as the role of pilots who were present on the bridge during some of the incidents. Further restrictions are given implicitly by the areas of responsibility of BSU, i.e. accidents involving German-flagged ships or accidents occurring in German territorial waters (i.e. coastal waters, inland waterways and harbours). In line with the Human Element Analysis Process (HEAP, MSC/Circ.878) the CAHR method was applied with the aim of reviewing all affected areas, i.e. technical, manning, training, management and work environment.

Vessel type	number of cases
Containership	23
Bulker	5
General cargo vessel	4
MultiPurpose vessel	4
RoRo-vessel	3
Tanker	3

Table 1. Vessel types involved in collision accident

The majority of the selected accidents were classed “severe” or “very severe” (Table 2).

Accident severity	number of reports
Less severe accident[a]	2
Severe accident[b]	14
Very severe accident[c]	5

[a] Accidents with consequences that can be resolved on board.
[b] Accidents with consequences requiring assistance by external parties.
[c] Accidents involving fatality, total loss of a vessel, or release of more than 50 tonnes of pollutant.

Table 2. Distribution of accidents by severity

Analysis process

The CAHR analysis is performed in two phases (Figure 1). Phase 1 comprises the identification and

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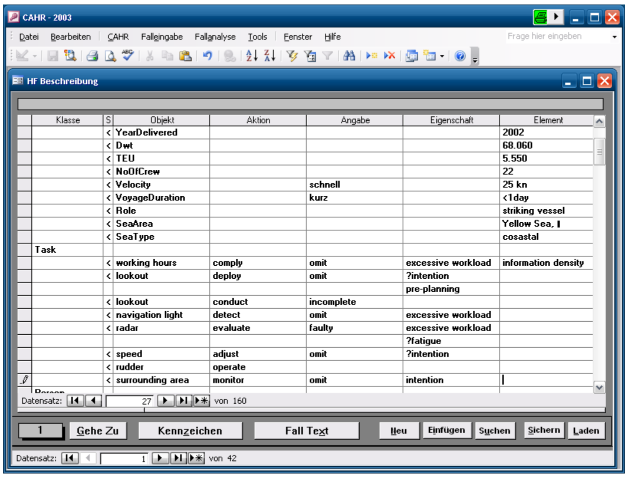
[2] The decision concerning this selection criterion was made based on the fact that the GL classifies and audits the largest part of the worldwide fleet of this type of vessels.

modelling of relevant events and performance shaping factors from accident reports; phase 2 comprises the connectionism analysis and the determination of possible control options.

Analysis phase I: Identification and modelling of events

Initially, the 21 accident reports were analysed individually. In this phase events essential for occurrence of each accident were collected, as well as performance shaping factors that were considered likely to be present at the time of the accident. Events in the context of analysis are not classed as “errors” in the human factors sense. Each event is broken down into different sub-events (there may be multiple events with different acting persons contributing to a single accident) is modelled in terms of a human-machine system and entered into a database. For this purpose an occupational model of the human machine system is employed (see centre box of Figure 1).

Accident data that is relevant with respect to human element influences is specified in a tabular format (see Figure 2). Extraction of such data from the reports (and possibly further complementary data sources) and correct classification of this data comprises a vital step of the analysis. Hence, the analyst needs to be familiar with the processes on the bridge. This requirement is in line with findings of other work, e.g. on the creation of marine accident databases (Rothblum *et al.* 2002). Prior to commencing the second phase of the CAHR analysis, modelled data should be reviewed carefully. In collaboration with a ship operator, data items were reviewed that were extracted from reports on accidents involving vessels of his fleet.



Klasse	S	Objekt	Aktion	Angabe	Eigenschaft	Element
	<	YearDelivered				2002
	<	Dwt				68.060
	<	TEU				5.550
	<	NoOfCrew				22
	<	Velocity		schnell		25 kn
	<	VoyageDuration		kurz		<1day
	<	Role				striking vessel
	<	SeaArea				Yellow Sea,
	<	SeaType				cosastal
Task						
	<	working hours	comply	omit	excessive workload	information density
	<	lookout	deploy	omit	?intention	
					pre-planning	
	<	lookout	conduct	incomplete		
	<	navigation light	detect	omit	excessive workload	
	<	radar	evaluate	faulty	excessive workload	
					?fatigue	
	<	speed	adjust	omit	?intention	
	<	rudder	operate			
	<	surrounding area	monitor	omit	intention	

Figure 2. User interface for data entry

Analysis phase II: Connectionism analysis and identification of control options

In a second step the connectionism analysis embodied in the CAHR method is applied to perform a horizontal search across the accident data. In this analysis step combinations of factors of the human machine systems are identified that frequently occurred in the accidents. It is expected that by this approach an investigation of systematically occurring combinations of factors can result in a more adequate understanding of the interdependency of contributing factors and of occupational root causes of accidents that may eventually lead to the formulation of suitable control options.

Analysis results

General findings

In the 21 reports, 60 relevant human machine events were determined. For these, in total 295 assignments of spurious actions were performed (Figure 3), and to the latter in total 466 PSFs were assigned – the most frequent ones are shown in Table 3.

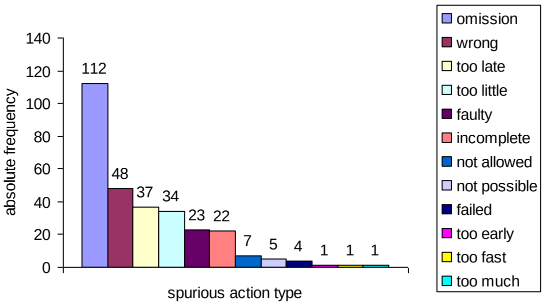


Figure 3. Distribution of spurious actions

PSF	#	PSF	#
Traffic density	68	Distraction	13
Intention	58	Pre-planning	13
Attention	46	Fatigue	9
Night conditions	33	Fixation	9
Experience	28	Expertise	9
Situational awareness	28	Instrument malfunction	8
Judgement	25	System inertia	7
Fog	23	Negligence	5
Excessive workload	17	Instrument setting	5

Table 3. Most frequently assigned PSFs (# of cases)

Distribution of events in relation to involved personnel

Out of the 60 events that were determined, 42 related to ship-“internal” actors, i.e. members of the vessels’ crews, most dominantly captains and officers of the watch (OOW), see Table 4. “External” actors (mainly pilots on the vessels’ bridges, but also land-based personnel such as radar advisors and personnel of vessel traffic services, VTS) performed 13 events. In a further eight events two actors were involved; but from the information provided in the accident reports, in three of these cases it was not possible to attribute erroneous actions specifically to one of the possible actors.

Persons involved	No of events
Internal: Captain/Master	20
OOW	20
Lookout	1
Rudder	1
External: Pilot	11
Radar Advisor	1
Nautical Officer (VTS)	1
Two persons:	
Captain/Master and pilot	4 (6)
OOW and pilot	1 (2)

Table 4. Broad characteristics of initial data

On average, the OOWs performed about nine errors per accident, captains performed seven and pilots performed six errors per accident (Figure 4). For the ship crew, errors of omission (i.e. errors “omission”, “not possible”, “failed”) occurred most frequently, followed by time errors (“too late”, “too early”, “too fast”). For the pilots these groups of errors occurred with similar frequency. For the remaining error classes the frequencies are lower and occur in the same orders of magnitudes for all persons: qualitative errors (“too little”, “too much”, “incomplete”), followed by errors of commission (“faulty”, “wrong”) and slips.

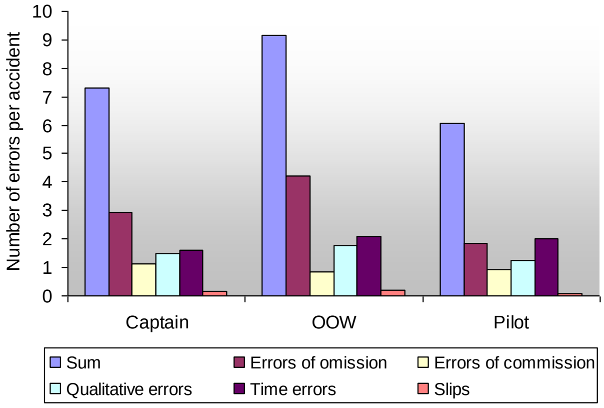


Figure 4. Distribution of error types per event by person

Priorisation of PSFs

In a subsequent analysis step the PSFs that were assigned to the errors were investigated in the context of freely specifiable side conditions (e.g. “PSFs that occurred with a high correlation to errors of omission committed by the OOW in short voyages”).

As a general principle for the priorisation of a PSF with respect to need for action, its absolute frequency (number of occurrences within all 60 events) is compared against its relative frequency (number of occurrences of the PSF within given side-conditions in relation to absolute number of occurrences), see Figure 5.

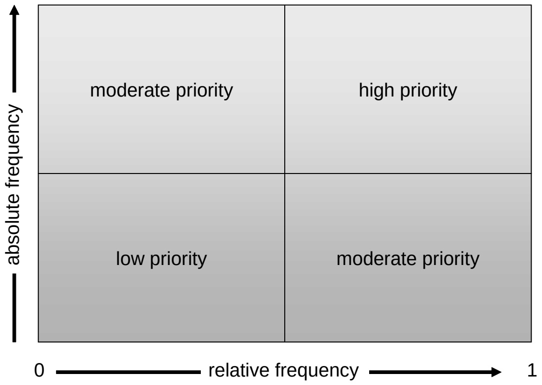


Figure 5. Diagram areas by priority

The highest priority is assigned to PSFs with a high absolute and relative frequency, since these occur frequently, both, within the whole dataset, as well as within the dataset that fulfils given side conditions. PSFs with low absolute and relative frequencies are treated with low priority. The remaining PSFs are assigned medium priority, since they either appear frequently in general, or they appear particularly within the context defined by the side conditions.

This principle is illustrated in Figure 6, by investigation of PSFs that were assigned in the context of omission errors (initially independent of the role of a person on the bridge). For this context, the predominant PSFs were “intention” (intentional violation of rules), lack of “attention” and a limited “experience”. Further PSFs that appear to be specific to conditions where omission errors occurred in the context of collisions include “excessive workload”, “fatigue”, “pre-planning”, “routine” procedures, “control system design”, “authority”, “principle of reliance” and “impatience”.

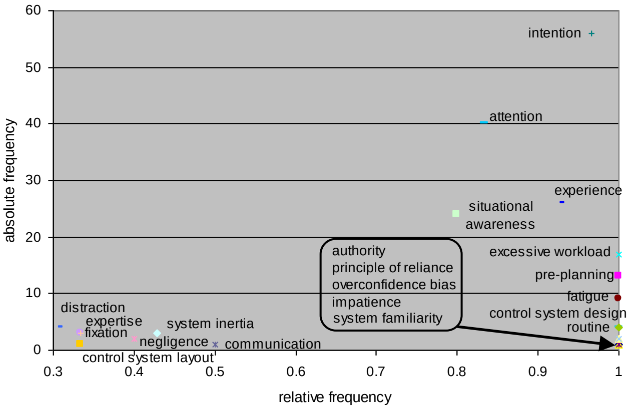


Figure 6. Occurrence of PSFs in connection to omission errors

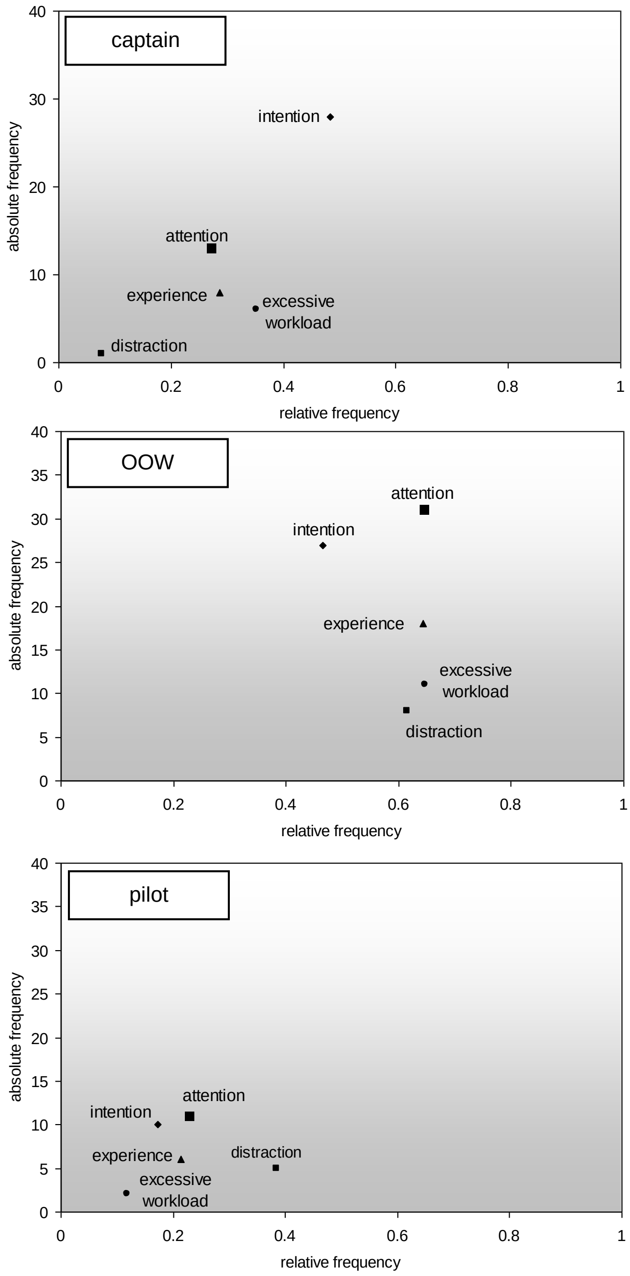


Figure 7. Comparison of PSF priorities by personnel

PSFs can also be investigated w.r.t. personnel. By example of five PSFs, Figure 7 illustrates that lack of "attention" in the course of collisions was assigned more frequently to OOWs, and was assigned with a lower, but similar frequency to captains and pilots. In this collision context, "excessive workload" appears to be a frequent factor for OOWs, but was assigned less frequently for captains and pilots. In a similar manner, a more detailed analysis of the PSFs that were assigned to the 60 events can be performed, for instance investigating the influence of voyage duration (= duration of the current leg of the voyage since last harbour) at the time of occurrence of events. The distribution of the events by voyage duration is given in Table 5.

Duration	number
Short (<1 day)	43
Long (> 1 day)	17

Table 5. Distribution of events by leg duration

As is shown in Figure 8 and Figure 9, factors such as "fatigue" and "distraction" were assigned less frequently for long voyage durations than for short voyages. This is in line with the expectation that long voyage legs provide crews a better chance for relaxing than short voyages, which often involve the bridge crew in a number of tasks during harbouring in addition to the navigational tasks at sea.

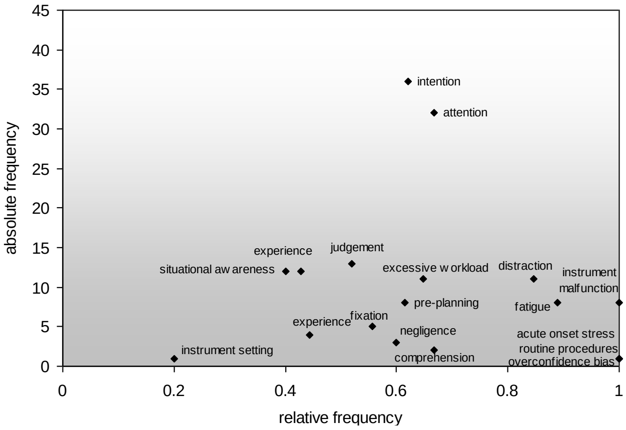


Figure 8. Prio. of PSFs for voyage duration < 1 day

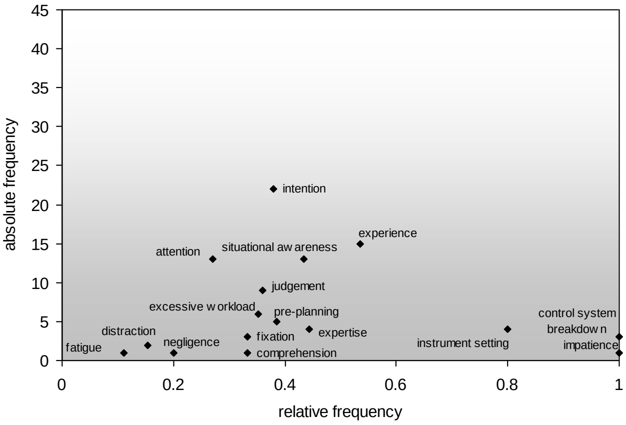


Figure 9. Prio. of PSFs for voyage duration > 1 day

DISCUSSION

The aim of this work was to investigate if the CAHR method may be suitable for the generation and validation of human reliability data in the maritime domain. Experiences with respect to suitability of the method, requirements on data sources and the analysts' experience are discussed in the subsequent sections.

General suitability of the method for HRA data generation and validation

Given the limited number and scope of reports which were selected for this proof of concept work, the relative frequencies can not be considered representative for the whole range of collision accidents. However, the qualitative results appear to be in line with findings of other studies of accidents related to bridge operations, such as (USCG 1995) and (MAIB 2004).

Requirements on data sources

In the context of this initial analysis, the accident reports provided by BSU (and, for that purpose, also several other agencies) are a suitable data source, since they contain a substantial amount of relevant contextual information. Notwithstanding, there are a number of recognised drawbacks in using accident reports as data source.

Data obtained from accident reports in general is not first hand information; the reporting authorities may not be provided all information they request, and for legal and assurance reasons certain pieces of information may not be published. Furthermore, despite detailed coverage of human element issues, e.g. in IMO Resolution A.884(21), in most accident reports the topic of human element influences is not addressed in much detail. One reason is the level of expertise required. Checklists, e.g. those provided in Annexes 2 and 8 of MSC/Circ.953, are intended to support the analysis of this issue, but do not capture sufficient detail to perform a CAHR analysis.

Finally, reported events are only the top of the accident triangle; it is a widely accepted judgement that for every reported event there are about 600 "near misses" (Ferguson and Landsburg 1998).

Hence, in order to obtain a more representative view of "everyday situations", a more suitable data source for this analysis would be "near misses" and incidents that are encountered by operators. Such an approach would require an implementation of a suitable safety management system being in place, with the provisions of internal incident reporting (or possibly anonymous reporting to a central external database), taking into consideration all the challenges of such reporting systems, e.g., see (Johnson 2003).

Required expertise

Phase I of the CAHR analysis requires the systematic extraction of human-factors incident or accident data in terms of the entities in the Human-Machine System model (Figure 1). To perform this task, expertise is required on both, the application of the CAHR method and the ship operations of concern. The methodological challenge may be addressed by a reporting software tool with a suitable user interface. However, the application of connectionism assessment in phase II of the analysis cannot readily be implemented in a supporting tool. The integration of human factors skills and ship operational experience in the analysis most likely can be achieved most effectively by adding a human factors expert to the incident/accident investigation team (both, for accident investigations by authorities and in-house analyses of near misses by operators).

CONCLUSION

In summary, it can be concluded that the CAHR method provides the theoretical foundation (and a prototype tool) for capturing and analyzing incident and accident data with respect to human performance. For a wide application in the maritime domain a number of technical challenges must be resolved. Possible solutions to some of these challenges are indicated in the discussion section above.

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