

HUMAN FACTORS AND EVERYDAY ROUTINE IN THE MARITIME WORK DOMAIN

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Abstract

The traditional approach to the study of human factors in the maritime work domain is the analysis of accidents. These analyses could provide us with valuable information, but they are not sufficient in the attempt to capture the causal relationship between performance shaping factors and human performance in the everyday routine work. Another and more suitable approach to the study of human factors everyday routine work in the maritime domain is the quasi-experimental field study where variations in performance (for example attention) can be observed as a function of natural variations in performance shaping factors (for example workload). I have demonstrated how these natural variations of workload very easily can be observed as a function of the different stages or phases of a voyage on one out of four selected Ro-Ro ferries in regular service. I have also suggested a very easy method for measurement of crew attention through measurement of communication at the bridge of the ship. When these methods were used in a pilot study of the relationship between workload and attention some interesting mechanisms was found. These findings could lead to development of hypotheses about the causal relationship between workload and attention, and the hypotheses could be tested by means of quasi-experimental field studies as suggested in this paper.

Keywords

Human factors, mental workload, attention, maritime work domain, quasi-experimental field studies.

INTRODUCTION

The traditional way of studying human factors in the maritime work domain is through the analysis of accident reports or even better through the analysis of accidents. This approach is quite reasonable since it seems to be common knowledge that a majority (often the figure 80% is mentioned) of accidents are actually caused by human factors or human error. The advantage of accident reports is that they are easy to get. It is possible to download reports for free from several databases on the Internet (for example databases in Canada, USA and Australia). The advantage is further that the accident report usually is written by a domain expert, who has the ability to evaluate the human performance in the particular case against the performance standard you could expect in the given situation from the crew. This traditional approach has also disadvantages, since it does not reveal human factors that do not induce reported accidents or near misses. Sometimes the human factor can be seen as a significant ingredient in an incident that is never reported at all. Another problem is that the human factor can induce as well as prevent accidents and near misses. The human factor is therefore not only the cause behind a problem. It can also be the solution. It could therefore be useful to find, discuss and develop new empirical approaches for collection of knowledge about the human factors contribution to and impact on the overall safety on board a vessel. This paper suggests a new empirical approach for collection of data regarding human factors in the everyday routine work in the maritime domain. The approach is based upon a theoretical framework of well-known models, and it is demonstrated to be suitable for studies of mental workload and attention.

Definition of human factors

Human factors can be defined as a discipline regarding human abilities and limitations in relation to the design of systems, organisations, tools etc. Important parameters are safety, efficiency and comfort (Salvendy 1997). However, the definition I am going to use through out this paper is human factors as a concept rather than a discipline. This means, that human factors are a number of human related factors,

which can also be denominated as the human element, in the safe and efficient operation of – in this case – a ship. Other factors than human factors could be technical factors or environmental factors. This corresponds with the use of the concept in the ADREP classification system used in the aviation domain (ADREP 2000). The empirical study described in this paper is a study of two relevant human factor concepts: Workload and attention. These are just a selection of two among a large number of concepts, but they are nevertheless important due to their regularity in the causal explanations of maritime accidents, near misses and incidents.

Definition of the maritime work domain

The concept of the maritime work domain was introduced in the beginning of the paper, but it is necessary to define it properly. I will start by defining the maritime work domain in broad terms as any kind of work task performed on board any kind of vessel. According to the report on the BERTRANC project (BERTRANC 2000) it is possible to define five maritime work tasks:

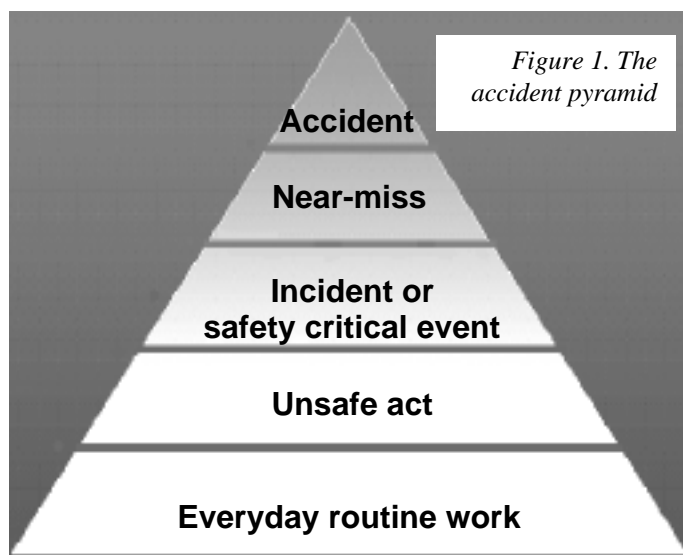
- Navigation (route planning, track keeping and collision avoidance)
- Propulsion (the responsibility for the integrity of the ships propulsion system and associated auxiliaries)
- Cargo handling (loading, keeping the cargo (including passengers) in good condition and unloading)
- Platform maintenance (keeping the ship, its equipment (e.g. the auxiliary equipment) and the crew (the hotel function) in operational condition)
- Ship management (the allocation of tasks and responsibilities, control and supervision and communication).

Although the maritime work domain covers all the above-mentioned aspects I will narrow my scope in this paper to the work performed in a certain part of the ship: The bridge from where the ship is navigated. However, this does not indicate that the work performed on the bridge is more important than work performed at other places on board the ship. The work performed for example in the engine room can be considered to be just as important.

THEORETICAL MODELS AND FRAMEWORK

The accident pyramid

A number of studies have revealed the fact that for each serious accident in the maritime domain, in aviation or in any other domain there is a number of incidents, a higher number of near-misses and an even higher number of safety critical events, unsafe acts etc. There are different opinions about the exact numbers, but it seems to be evident, that relationship in size between the different levels is as described above. This relationship is often illustrated as a pyramid (see figure 1).



It is important to notice, that the number of everyday events with a safety critical potential could be even higher than the number of safety critical events or unsafe acts. But it is also important to notice that the principal of the model is, and that seems to be an empirical fact, that an event or act with a safety critical potential not necessarily will result in an accident. The organisational accident causation model (Reason 1997) illustrates this mechanism further.

The organisational accident causation model

The organisational accident causation model (Reason 1997, Johnson & Botting 1999) has five levels described as:

1. Organisational factors (communications, management decisions/structure, organisational processes, incompatible goals etc.)
2. Local factors/current conditions of work (fatigue, equipment, procedures, workload, supervision etc.)
3. Active failures (slips, lapses, mistakes, violations)
4. Defences
5. Accidents

This model is very well known, and it found in a large number of versions with variations in denominations and concepts. The model describes the causality behind an accident. This description includes a number of performance shaping factors: Organisational factors and local factors and the performance regulated by these factors - in this case described as active failures or human error. Other performance shaping factors relevant in the maritime domain could be for example environmental factors, interaction with colleagues (interpersonal factors), and interaction with the vessel and its equipment (ADREP 2000).

The model is build for analysis and understanding of the causality behind accidents. But it can be generalized to cover also everyday routine work, if level 1 and 2 are considered to cover performance-shaping factors and level 3 is considered to cover the performance (including behaviour and communication) of one person or a group of persons - for example the crew on board a ship - in situations where the performance is adequate as well as situations where it is inadequate. One example of a performance-shaping factor is workload, and an example of performance shaped by this factor could be attention. These two concepts will be the subject of the empirical study described later in this paper.

Theoretical framework

I have now described two very well known theoretical models: The accident pyramid and the accident causation model. *The accident pyramid* describes quantitative relationships between events such as incidents, near misses and accidents, and which could also be expanded to include normal everyday routine actions and events. *The accident causation model* describes the causality behind an accident. It is from this model possible to describe performance-shaping factors and it is possible to describe performance both in a sense where it is adequate in the given situation and in a sense where it fails. In the last case the performance can be described using human error taxonomies. Some well-known examples of human error taxonomies are: The Human and Organizational Error Taxonomy (Reason 1997), Slips, lapses, mistakes, and violations (Reason 1990), Errors of omission, errors of commission, extraneous acts (Swain 1982, Swain & Guttman 1983) and Skill-, rule-, and knowledge based behaviour (Rasmussen 1981). These taxonomies are actually in use in the maritime domain as tools in the retrospective analysis of accidents or in proactive human reliability assessments (one example is Merrick et al. 2000).

The performance shaping factors includes *human factors* which could be considered to be internal within the individual human being and human factors that are related to the interaction between the individual and other individuals (inter personal interaction), interaction with equipment and vessel, interaction with procedures and other written material, and interaction with (or exposure to) the physical environment inside and outside the vessel (ADREP 2000).

As mentioned in the introduction the most established method for collection of knowledge about human factors in the maritime work domain is the retrospective analysis of accidents. A large number of tools are developed and have demonstrated their usefulness in this work. The organisational accident causation model and the loss causation model (Det Norske Veritas 2001) are together with the human error taxonomies good examples. I could also mention a number of well-established methods for analysis of accidents and accident reports (Johnson 1999a) - for example the STEP-method proposed by Hendrick & Benner (CASMET 1999), Reason's accident causation and analysis model (Busse & Wright 2000), Fault-tree representation (Johnson 1997a, Love & Johnson 1997), Petri nets (Johnson 1997a, Love & Johnson 1997) and Conclusion, Analysis, Evidence (CAE) Diagrams (Johnson 1997b, 1999b).

However, the knowledge we gain using these tools, models and methods is strictly related to accidents, near misses and incidents in the extent these are reported. We can identify relevant human factors phenomena this way, but we need to have in mind that when we look at accidents, near misses and incidents we are according to the accident pyramid only studying "the top of the iceberg". There is a huge underlying amount of everyday routine work, actions and behaviour that we are simply not able to capture this way. If I for one moment return to my example: The relation between workload and attention, we could easily imagine, that we actually could get valuable information about the relationship from the analysis of accidents, but that we on the other hand could overlook some important mechanisms or functions related to this relationship the way it works in the everyday routine at the bridge on a ship.

THE EMPIRICAL STUDY OF WORKLOAD AND ATTENTION

Both workload and attention are important concepts in the human factors tradition. Although other and more recent developed concepts (such as situational awareness) are gaining importance, it seems that workload and attention are still subject to discussion in handbooks of human factors, on conferences and in journals. Findings done on the basis of maritime accident reports indicates, that workload and attention also have significant importance in the causality behind maritime accidents such as collisions and groundings. But the indications in these accident reports could be limited to be only the top of the iceberg.

It has over some years been assumed that the major problem about workload and attention is, that too high workload would induce overload problems related to division of attention. This has been reflected in the training in complex, stressful and critical situations in Bridge Resource Management (BRM) and Crew Resource Management (CRM) courses. But it seems evident from numbers of accident cases that the opposite is quite often the problem. Accidents are often caused by lack of attention due to very low levels of workload. These accidents happen on days with calm weather and sea, good visibility, no technical problems with vessel or equipment, a well rested, well-trained and competent crew, in well known waters etc. It seems evident that there is comfort zone of mental workload in which the attention as one mental function among others is on an appropriate level in the given context. It also seems that there is some causal connection between workload and attention and that very low levels of workload induces very low attention and that very high levels of workload induces other problems related to attention for example problems about division of attention due to limited mental resources.

A number of methods could be used for the study of this relationship between workload and attention in the everyday routine work at the bridge on board ships, but some might be more suitable than others. Some relevant examples could be experiments performed in the maritime simulator, case studies performed in the field and quasi-experimental field studies.

Experimental work in the simulator

The maritime full-mission simulator is very well suited for performance of human factors experiments - for example with high mental workload - since the environment can be controlled fully in any matter. The wind, current, visibility, traffic density etc. can be adjusted to fit the purpose perfectly. It is also possible to make several repetitions of a scenario controlling and isolating every single variable, and it is possible to stop the simulation and perform interviews at any moment. This could for example be an advantage in the study of

situational awareness. The simulator has further more some great advantages when it comes to the recording of the operators' performance. Every single manoeuvre can be recorded and analysed by domain experts, and it is even possible to make video and audio recordings for transcription of communication and behaviour. The problem is however that simulator only "pretends to be". It is not a real ship although acting as such, and it is not a real environment although looking as such. The work performed in the simulator is in fact a role-play at a technically very advanced scene. It is close to the everyday work, but it does not match perfectly. The results obtained from experiments done in the simulator have therefore a very high reliability, but they might not be perfectly valid. Especially not when the subject of the study is the relationship between workload and attention in everyday routine work, since the work performed in the simulator is an exemption from the everyday routine.

Case studies

Case studies of maritime work can be performed as studies of a single voyage, with a single vessel and a single ship. Studies of this kind can provide us with information about which phenomena could possibly be observed on board a ship. The phenomenon exists if we are able to observe it at least one single time in the case study. But we are on the other hand not able to deny the existence of phenomenon's not observed. They could be present at another voyage with the same vessel and crew, on another vessel or among the members of another crew. But we are from a single case study not able to determine how rare or likely any given phenomenon is, and we are certainly not able to examine quantitative relationships or correlations between variables.

Quasi-experimental studies in the field

Even though the real environment is not controllable in the way it is in the simulator it is nevertheless possible to perform field studies of high scientific quality onboard ships. The method is considered to be quasi-experimental because there is a natural variation in the different variables such as traffic density, visibility, wind, current etc. This natural variation could however be over a very long period making the method very time consuming. It is possible to make observations of the work performed by the crew and transcribe these observations of behaviour and communication. It is also possible to perform interviews with the crewmembers as long as it does not affect the work they do. The possibilities of collecting data about manoeuvres are more limited than in the simulator, but voyage data recorders if present could in principal provide these data.

The quasi-experimental study in the field seems - on basis of the discussion above - to be the most appropriate when it comes to the quantitative study of the relationship or correlation between two variables where workload as a performance-shaping factor is considered to be the independent variable (IV) and attention as a part of the overall human performance is considered to be the dependent variable (DV). It should idealistically be possible to observe variations in attention as a function of variations in workload. But this would require proper methods at an operational level for measurement of both workload and attention.

Variations in workload

A number of different methods for measurement of workload are suggested in the literature. Some of the methods measure perceived mental workload in a subjective way (for example NASA-TLX) and other are psycho-physiological measures of for example heart rate variability (e.g. the 0.1 Hz component) (Salvendy 1997). These methods measures how the individual responds or reacts to a given amount of workload in relation to the individuals' available mental resources in the given situation. This reaction could be in a behavioural way or in a physiological way. These methods do not measures of the amount of workload it self. This "objective" workload is actually produced by a number of parameters, when it comes to everyday routine work at the bridge on a ship. Examples of parameters could be: Traffic density, complexity of the voyage, visibility, sea state, wind, current, alarms, interaction with navigational equipment and administrative tasks. These parameters could vary within different cycles: The year, month or week, the day or the watch turnover, or even within the single voyage between two harbours. A ferry in regular service between two harbours will repeat the same voyage between these two harbours over and over again. You would therefore expect variations in some of the parameters due to changes in between voyages (for example

changes in weather), but the single voyage it self does also contain natural variations in workload independently of the more slowly changing parameters such as changes in weather.

Each voyage can be divided into different stages of phases with different workload and demands for human performance. A voyage can basically be described in three phases: The departure from harbour, the transit in between harbours and the arrival to harbour of destination. The duration of each phase depends on the actual route and on the type of vessel, where it is possible to distinguish between double-ender and single-ender. The single-ender vessel is always performing two sways in the one direction and none in the other. The double-ender is not performing any sways at all. Each of the three phases can be divided further into phases of crossing traffic lanes, entering marked fairway or channel etc. depending on the actual route. Although the crew is competent, well trained and experienced you would expect that the different phases of the voyage represents different levels of mental workload. The workload in transit on open water in good visibility and without traffic would be significantly lower than in crossing a lane with heavy traffic or positioning the vessel in the harbour under difficult conditions. But you could also expect that these variations in workload within the voyages could be larger on some routes than on other, and that the overall level of workload also could be larger on some routes than on other. A comparison of four different routes revealed that this was also a fact. Four different vessels, all operating as Ro-Ro and passenger ferries in Scandinavian waters, on four different routes were examined. Some describing properties of the four routes are summarized in the table below.

	Route A	Route B	Route C	Route D
Duration of voyage	20	45	45	120
Number of vessels operating on route	3	1	2	3
Duration of stay in harbour between voyages	10 (a few times 20)	15	15	60
Domestic/international	International	Domestic	Domestic	International
Type of vessel	Double ended ro-ro	Conventional ro-ro	Conventional ro-ro	Conventional ro-ro

- *Route A* can be described as a short and very busy route crossing a traffic separation scheme with very high traffic density. The route includes typically and under good conditions only one alteration of course in the middle of the transit segment of the route.
- *Route B* is a route with a much lower frequency than route A. The voyage from one harbour to the other can under good conditions be done on one single course with no alterations of course at all. The traffic density is very low (a few crossing vessels per day) except from seasonal and periodic congregations of small pleasure crafts.
- *Route C* crosses an area with high density of traffic. It is more complicated in navigational terms than route A and B since it includes navigation in and out of a narrow dredged channel at an area where fishing nets are very common.
- *Route D* is the longest of the four routes. It is complicated in navigational terms since it includes navigation in and out of a narrow dredged channel, the crossing of an area with high traffic density, navigation in and out of another channel with very high traffic density and navigation in a very large harbour with crossing traffic and a high density of other vessels. The route is further more covered by a Vessel Traffic Service (VTS) centre, which has the responsibility for monitoring and regulation of the traffic. This induces an amount of official and standardised communication between the ferry and the VTS.

I chose to evaluate the variation of within voyages on each route using a very simple three point scale where 1=low workload, 2=medium workload, and 3=high workload. The voyage of each route was divided into five segments: Departure, transit, mid-water, transit and arrival, and the workload of each segment were

evaluated using the described three-point scale. The variation measure index was then calculated as the sum of differences between each segment of the voyage.

Segment of voyage	Route A	Route B	Route C	Route D
Departure	2	2	2	2
Transit	3	1	2	1
Mid-water	3	1	2	3
Transit	3	1	1	1
Arrival	2	2	3	3
Variation measure index	2	2	3	7

From that it can be seen that the workload on route A due to the high traffic density in general is very high, but the variation within each voyage due to the short duration is very low. The workload on route B was due to very little traffic in general low with low variation within the single voyage. Route C has a higher variation than route A and B due to an asymmetrical distribution of workload on each voyage. Route D has the highest variation in workload since it includes both segments of transit with low workload, passage of an area with high density of crossing traffic mid-water and a complex arrival to the port of destination. I can conclude that it is - using a very simple method and scale - possible to identify variations within single voyages of a route simply induced by variations in workload in the different stages of the route. I had selected four different routes for this simple survey, and the result was, that route D represented a much larger variation in workload within every single voyage than route A, B and C. Route D could therefore be considered to be more suitable for the purpose of studying variations in attention as a function of variations in workload.

Variations in attention

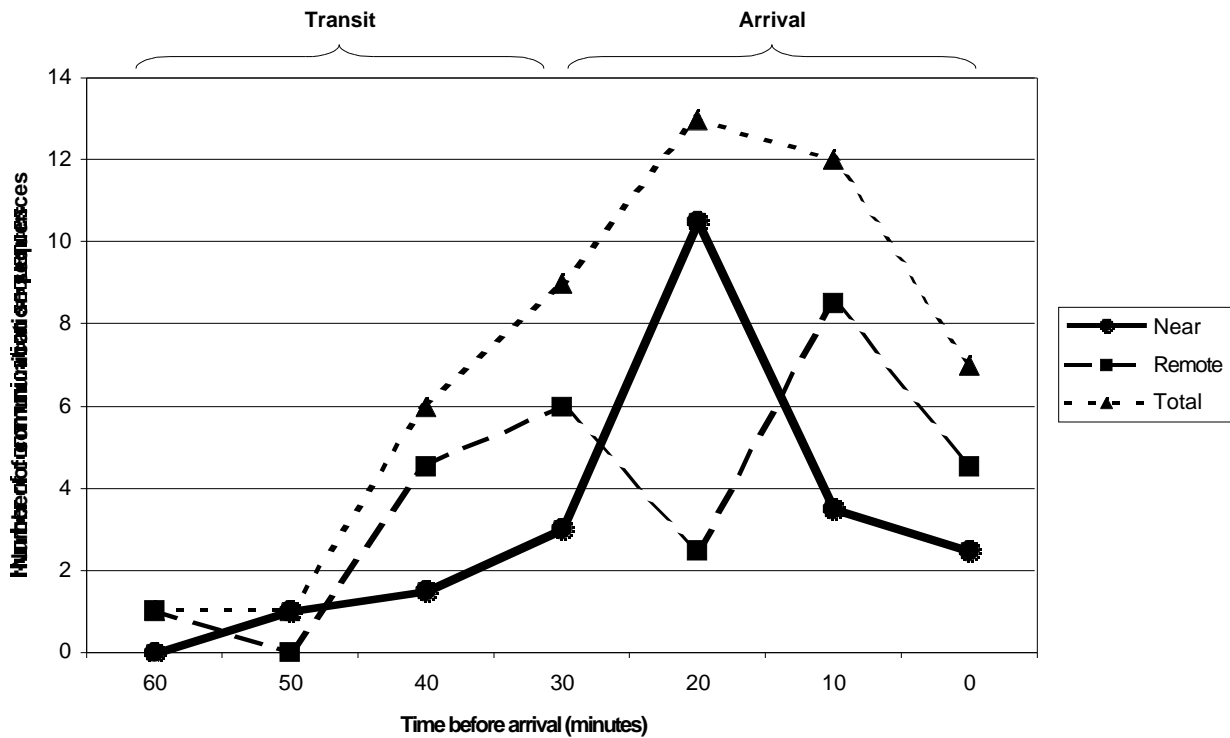
While workload can be measured as a combination of several objective and quantitative parameters in the environment and on the workplace, it is more difficult to measure attention as an internal psychological phenomenon in one single person or in a group of persons - for example the crew on the bridge of a ship. One common used method for the study of attention is eye-movement detection. This method - which requires expensive equipment for the measurements - takes advantage of the assumption that we are paying attention to what we look at in any given moment. That is true to some extent, but we are nevertheless able to pay attention to something we do not look at - for example a verbal message - and we are also able to look at something without paying attention to it. I would like to demonstrate how it by very simple - and much cheaper - means is possible to measure attention by measuring communication on the basis of an assumption similar to the one regarding eye-movement detection: Communication about a given subject indicates, that attention is paid to it, but it is evidently not possible to conclude the other way around.

I would like to introduce two measures of communication: The number of communication sequences per 10 minutes and the distribution of these communication sequences between subjects close in time and relation to the given situation and subjects far from the given situation. Communication about the actual voyage, navigation and navigational aids, traffic and the weather is - due to their relevance - considered to be *near* to the situation while communication about colleagues, division of work, organisational aspects and private matters are considered to be *remote*. Communication sequences about the vessel and its equipment are considered to be both near and remote with the weight of 0.5 in each category. The communication can be observed, counted and recorded in the two categories for each ten minutes period of a voyage using for example a simple spreadsheet on a portable PC or simply a scheme on paper.

I assumed that there would be a relationship between workload and attention in the way that very low workload would induce a very low level of attention. I have claimed that it is possible to use communication as an indicator of the level of attention. It should therefore be possible to observe an increase in communication as a result on an increase in workload. To exemplify that I made a study of a voyage on route

D, which is the route with the greatest variation in workload among the four selected routes. I systematically recorded the communication on the bridge of the ship from 60 minutes before arrival (in transit where the workload was evaluated to be low) to arrival in the port of destination (where the workload was evaluated to be high). I would expect the amount of communication to increase gradually from transit to arrival. And that was in fact - not surprisingly - what it did to some extent.

The total amount of communication is shown in the diagram below with a dotted line marked by triangles. An analysis of correlation shows, that there is a correlation (Pearson's $r = 0.7561$, $0.01 < p < 0.05$) between the time before arrival and the total amount of communication. The correlation between the time before arrival and the total amount of communication is even stronger if only the time interval between 60 and 20 minutes before arrival is taken into account (Pearson's $r = 0.97373$, $0.001 < p < 0.01$). The same pattern, with an increase of communication until 20 minutes before arrival, is also seen for communication of the category *near* (communication of high relevance) alone, but the correlation is not quite as strong and significant (Pearson's $r = 0.86136$, $0.05 < p < 0.10$) as the increase in the total amount of communication.

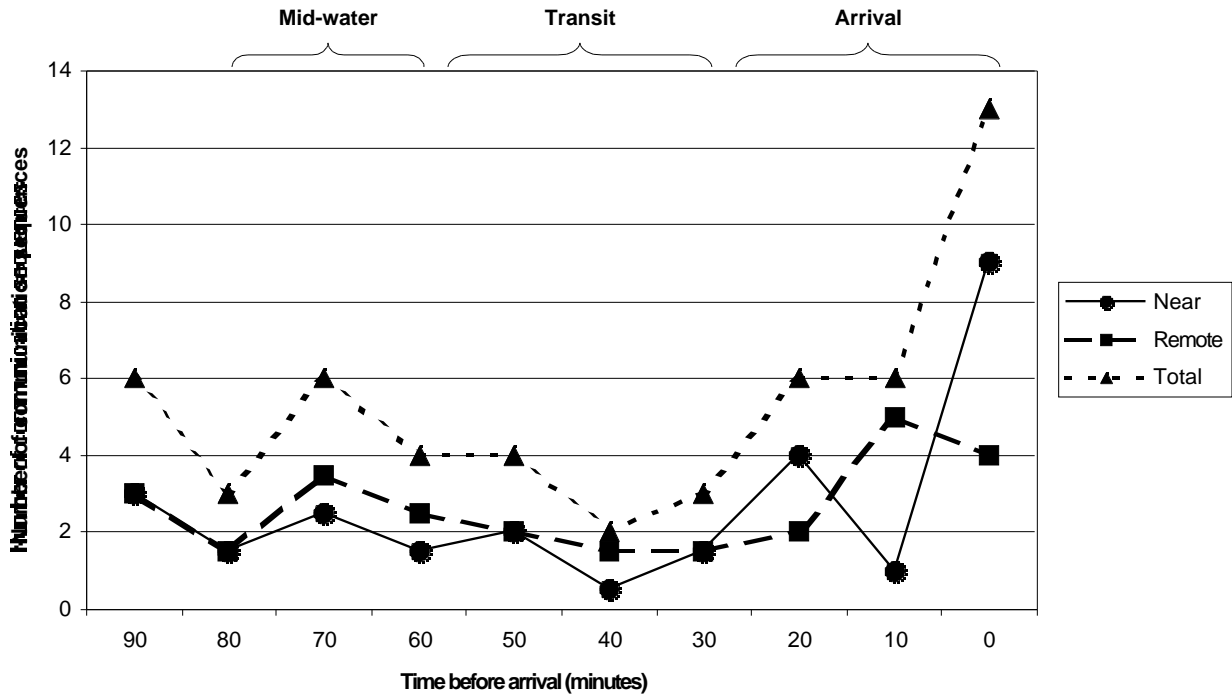


The surprising thing is that the amount of communication increases until about 10-20 minutes before arrival and then decreases at the time of arrival to a level equivalent to the one at 30-40 minutes before arrival. This could indicate, that the arrival segment of the voyage should be divided into smaller segments with differences in degree of workload, where the highest workload on this actual voyage was at the entry to the port 20 minutes before arrival and the lowest level was when the vessel was positioned alongside the quay under very calm and easy weather conditions.

But what is really interesting is that the fast increase in the communication of high relevance results in an equal fast decrease in the more remote communication ($\chi^2 p=0.025$). This could indicate that full attention is paid to the performance of the task (entry to the port), that attention has a limited bandwidth, and that this limitation demands an increase in irrelevant communication when the bandwidth is fully in use by relevant communication.

In the example below taken from the same vessel on the same route but at another voyage and arrival to the other port of destination another mechanism is seen. At about 10 minutes before arrival to the port a sudden

decrease in communication in the category *near* is seen. At the same time an equal sudden increase in communication in the category *remote* results in an unchanged total amount of communication ($\chi^2 p=0.079$). It is not possible to see the causality behind this correlation, but one possibility could be that the sudden drop in the relevant communication is outweighed by an equal sudden raise in irrelevant communication for the maintenance of an appropriate level of attention. Again it can be mentioned, that there is a correlation (Pearson's $r = 0.91902$, $0.01 < p < 0.05$) between the time before arrival and the total amount of communication, but only in the time interval from 40 minutes before arrival to arrival.



Conclusion

The traditional approach to the study of human factors in the maritime work domain is the analysis of accidents. These analyses could provide us with valuable information, but they are not sufficient in the attempt to capture the causal relationship between performance shaping factors and human performance in the everyday routine work where accidents, near misses and incidents fortunately are very rare. Another and more suitable approach to the study of human factors in everyday routine work in the maritime domain is the quasi-experimental field study where variations in performance (for example attention) can be observed as a function of natural variations in performance shaping factors (for example workload). I have demonstrated how these natural variations of workload very easily can be observed as a function of the different stages or phases of a voyage on one out of four selected Ro-Ro ferries in regular service. I have also suggested a very easy method for measurement of crew attention through measurement of communication at the bridge of the ship. The overall amount of communication is measured as well as the distribution of communication categorized as near or remote according to the subject or content of the communication.

Accident analysis (retrospective)	Causal level	Conceptual level	Operational level	Quasi-experiments
	Performance shaping factors	Mental workload (IV)	Variation in phases of voyage (observation)	
	Performance	Attention (DV)	Variation in communication (observation)	

When these methods were used in a pilot study of the relationship between workload and attention three interesting mechanisms for possible further quasi-experimental field studies was revealed. First it seemed to be possible to find evidence for the hypothesis that workload and attention are causal related to each other in a correlative way such as very low mental workload results in very low level of attention and high amounts of workload induces higher levels of attention. Second, it was seen in one case that a sudden increase in relevant communication resulted in an equal sudden decrease in irrelevant communication. This could indicate that an upper limit of mental capacity was reached and that the decrease in irrelevant communication was a counter act against mental overload. And finally, third, it was seen in another case that a sudden decrease in relevant communication could be observed in connection to a corresponding increase in irrelevant communication. This could indicate that a compensating mechanism prevents mental under-load and lack of attention by substituting the lacking relevant communication with irrelevant communication (which requires attention) to obtain a sufficient and unchanged level of attention. These findings could lead to development of hypothesis about the causal relationship between workload and attention, and the hypothesis could be tested by means of quasi-experimental field studies as suggested in this paper.

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