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Fatigue at Sea - a Manning Problem

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ABSTRACT

Data about human and organizational factors from in-depth analysis of 93 grounding accident investigation reports are used to construct logistic regression models of human fatigue. A hierarchical model of the strongest fatigue-influencing factors in maritime transport is developed. Fatigue is most strongly influenced by less than adequate (LTA) manning levels and variable working conditions. LTA manning and Variable working conditions are shown to have strong influence on human fatigue on board. The regression models also show that officers working 12-12 shifts have a significantly higher probability of having variable work hours which in turn have a negative impact on their fatigue levels.

1. Introduction

Accidents are rarely a result of a single system failure or a single deliberate human action. Instead, when small, apparently unimportant events and crucial soft factors combine, serious accidents may occur (Cacciabue 1998). By soft factors we mean organizational and human factors. These are factors, which may be seen as latent conditions in an organization (system). They may be present for many years before they in certain situations penetrate through a system's defense and result in an accident (Reason 1990, 1997). The importance of management and organizational factors on the risk is well acknowledged in the scientific community (Øien 2001). However, these factors are difficult to model because of their complexity and broadness. Their exact definitions also vary, which means that gathering the existing relatively small amount of statistical data is difficult. Even though human factors as a subject emerged in the 50ths (Meister 1989), the area of research is still young.

Human fatigue is recognized as one of the most important safety hazards in transportation (Jones et al. 2005; Åkerstedt 2000; Jackson et al. 2013; M. J. Akhtar and I. B. Utne 2013). It is a human factor which is widely in place among the crewmembers on a ship's bridge. Seafarers' fatigue levels, in general is higher than fatigue in workers (working in shifts) onshore (Smith et al. 2006; Seahealth 2010). The maritime community is concerned about the impact of raised human fatigue levels on the risk of accidents. It is not uncommon for seafarers' being alone on the bridge to fall asleep on watch (MAIB 2004; Gould and Koefoed 2007). Maritime accidents have a potential to develop into disasters. Oil spills, loss of human life and large expenses for society may be results of ship grounding or a collision. Even if the seafarer does not fall asleep, human fatigue affects performance, even though its influence is not yet well understood (Margaretha Lützhöft et al. 2007)

One way human fatigue (hereby denoted only as fatigue) manifests itself is as a decrement of human performance when a person has worked for a considerable length of time (Okogbaa et al. 1994). Fatigue is a defense mechanism of the body. It constitutes the human body's signal that serves as an alert when bodily limitations are being surpassed (Vagias 2010).

In general, fatigue is an important phenomenon which has to be considered in risk analysis of technology-rich and industrialized systems, especially in workplaces operating around the clock, combined with the widespread use of automation (Dinges 1995). However, to this date there are no agreed upon definitions of fatigue in the scientific community. Hence, it is

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problematic to compare research results (Dawson and McCulloch 2005; Dorrian et al. 2011; Dawson et al. 2011). Nevertheless, it is recognized that fatigue is a multidimensional construct, complex in nature (J. Akhtar and I. B. Utne 2013). One definition of fatigue is that it is a personal experience and is a function of a number of variables (Griffith and Mahadevan 2011), like for instance time of day, amount of work done, hunger and sleep deprivation . Another definition is that it is a hypothetical construct which nevertheless can be inferred because it produces measurable phenomena (such as sleepiness), even though it may not be directly observable or measurable (Williamson et al. 2009). Yet another definition is that human fatigue is 'a biological drive for recuperative rest' (Desmond and Hancock 2001; Noy et al. 2009; Williamson et al. 2009).This article will make use of the latter definition of fatigue, because it is more practical when analysing accident investigation reports, which do not always directly mention or report on fatigue at the time of the accident (see Section 4).

Since fatigue is a complex phenomenon, the risk associated with it is not proven to be necessarily highest when fatigue is highest. However, a growing amount of research suggests that increasing levels of fatigue is associated with an increase in the probability of errors (Williamson et al. 2009).The main objective of this article is to model fatigue at sea by use of logistic regression in order to discover conditions which are detrimental to fatigue and hence also for the safe operation of the vessel. The article aims at finding the conditions on board ships which impact fatigue the strongest, thus helping decision makers, such as ship owners and authorities, to find efficient measures against fatigue.

The remainder of this article is structured as follows: Section 2 explains the method used in the article. It also contains a Table of known fatigue-influencing factors in the scientific literature. Section 3 presents the data gathered for the study. Section 4 presents the regression analysis and the regression models developed for fatigue. Section 5 discusses the results and presents the conclusions.

2. Method

Statistics used in accident analysis can be used to find common conditions and patterns that may reveal important hazardous conditions, although the causal relationship remains difficult to establish.

The present study includes a set of fatigue influencing factors (see Table 1) which are selected based on a review of scientific literature (Williamson et al. 2009; Rothblum et al. 2002; Horizon 2012; Allen et al. 2008; Gander et al. 2011; IMO 2001; Åkerstedt 2000; Dawson et al. 2012; Margareta Lützhöft et al. 2011; Margaretha Lützhöft et al. 2007; Smith et al. 2006), with main emphasis on from Akhtar and Utne (2014). Akhtar and Utne (2014) assessed 93 accident investigation reports with regards to 63 pre- determined fatigue influencing factors. If a fatigue influencing factors was deemed to be present in the accident, it was coded 1, otherwise as 0. In the study in the present article, the fatigue influencing factors are denoted as variables because regression analyses are then run to model various variables and relations, such as the variable Fatigue (henceforth the variable will be mentioned with a capital letter, while the general phenomena of fatigue will have lower case letter). By conducting the regression analysis in a systematic way, the relations between the variables in the dataset emerge. Not all of the 63 fatigue influencing factors from Akhtar and Utne (2014) are used as variables in the present study due to multicollinearity issues (see Section 4.1.1).The present study first conducts a regression analysis, keeping Fatigue as the dependent variable, i.e., the regression model tries to explain the variation of Fatigue in the dataset by using other variables from the same dataset. Second, regression analyses are conducted for each of the variables recognized as important variables to Fatigue (see Figure 1). In so doing, a hierarchical model, which explains Fatigue amongst the crew on board, is developed.

Table 1. Fatigue influencing factors (variables) in the study. The descriptions are adapted from Akhtar and Utne 2013.

Variable	Description
LTA Manning resources	Top management should provide enough manning resources to enable the Bridge Management Team (BMT) to perform their task in a satisfactory way, complying with rules and regulations for working hours. This means that the BMT does not have to undertake several additional duties while at work. Where this is not the case in the accident investigation report, top management is interpreted to provide less than adequate (LTA) manning resources for the BMT.
LTA Safety climate	An important fatigue-influencing factor is safety culture and safety climate. Safety culture reflects the attitudes, beliefs, perception and values that persons share in relation to safety at all levels of the organization (Cooper 2000). A safety climate is only one aspect of the safety culture in an organization which can be defined as a constructed system of meaning through which the hazards of the world are understood (Pidgeon 1998). There exists an important relationship between safety climate and performance (Hetherington et al. 2006). There is, however, a lack of universal consensus regarding the terms safety culture and safety climate. Often the terms are used interchangeably in the literature (Health & Safety Executive 2005). Where the accident reports describe the BMT's attitude towards safety being indifferent, and safety management is regarded as a burden or superfluous, the BMT is interpreted as having a LTA Safety climate.

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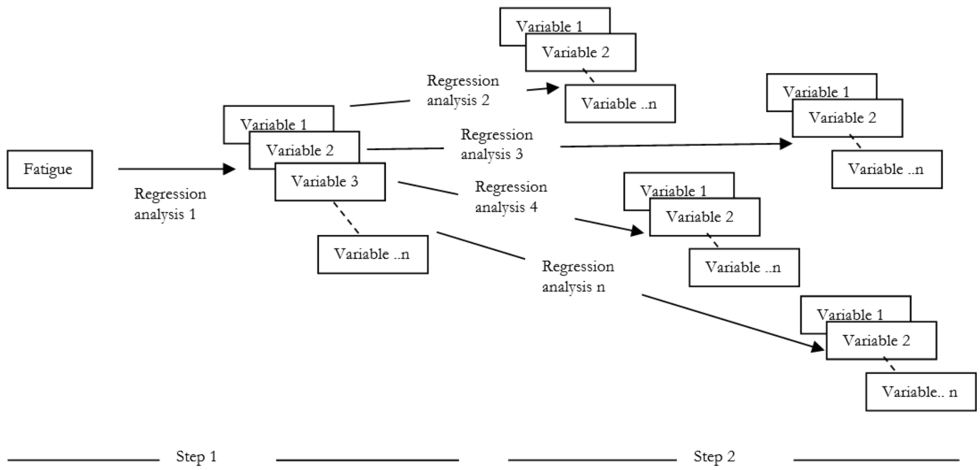
Figure 1: Two-step method to explore the dependent variable in a dataset using regression analysis



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Variable	Description
LTA Training focus	Good International Safety Management Code ISM practice includes (TSB 1998): • the master is properly qualified for command and is fully conversant with the company's Safety Management System (SMS) • the master is given necessary support so that he or she can perform the duty safely • the crew is capable of safely executing normal operational and emergency- related tasks • the crew is given proper familiarization of the vessel and its equipment • he training needs of the crew are identified A well-trained BMT is central in the ISM code (Kristiansen 2001). Training is also directly regulated in the STCW Convention (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers). The STCW Convention contains a number of requirements for training, among them: the establishment of quality standards throughout training, assessment and certification activities; the mandatory use of simulators to demonstrate competence in radar and ARPA; the requirement for recognition endorsements, and the explicit responsibilities placed on shipping companies (O'neil 2003). Lack of any of these points from the ISM or the STCW Convention in the accident reports are interpreted as a lack of (LTA) training focus.

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Variable	Description
LTA Vessel certification	Vessels have to comply with a number of rules and regulations. Among others: the IMO Conventions like SOLAS, STCW, MARPOL, COLREG, ISM and ISPS. There could also be other national laws, directives from, for instance, the European Commission and requirements from the classification societies. If one or more of these requirements are reported missing in the accident investigation reports, the company is classified as having LTA Vessel certifications.
LTA Quality control	Quality can be seen as a parameter of safety in the company. Quality planning, control and improvement are all dependent on top management setting up quality plans and providing infrastructure and resources for measurement. An effective auditing system detects nonconformities with the rules and regulations and the company's policies. If the non-conformities have been common the BMT and the company's monitoring and auditing system has not detected and implemented measures, or if the Safety Management Certificate (SMC) is not valid, the company is interpreted as having LTA–Inadequate quality control.

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Variable	Description
Variable working hours	Variable working hours are often associated with short sea passages, high levels of traffic, reduced manning, and rapid turnaround (Hetherington et al. 2006) (IMO 2001). Short passages, operating seven days a week, day and night, in combination with low manning levels frequently lead to variable working hours where the crew often will have their resting periods disturbed. Opportunities for the crew to rest is directly correlated to the vessel's schedule and circumstances (MAIB 2001). If not stated directly in the accident investigation report, the presence of all of these circumstances is seen as providing variable working hours for the crew.
Efficiency pressure	Lack of human resources, time pressure, the company's financial situation and relatively frequent staff turnover in the bridge's navigational team may lead to pressure on the crew to improve their efficiency. Delays and safety precautions may directly conflict with the demand of improving efficiency and saving money. When safety is compromised because of the BMT wanting to avoid delays and unwanted costs, it is interpreted as the BMT being under pressure to improve efficiency.
Shift scheme (6–6, 12–12, 4 rotations)	Seafarers work in shift patterns, which may contribute to fatigue and poorer health (Phillips and Sagberg 2010). The work regulations limit the exposure somewhat, but typically do not take into account the circadian rhythm, nor the rate of accumulation of sleep debt, the frequency of opportunities for full recovery from sleep debt, and they do not take into consideration non-work related time (Gander et al. 2011). Three different watch systems are recognized in the article: the two-watch system 6 on/6 off, the four-watch system (4 on/8 off/8 on/ 4 off or similar) and the two-watch system 12 on /12 off. Studies show that two-watch systems typically tend to create higher fatigue levels (Margaretha Lützhöft et al. 2007).

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Variable	Description
LTA BRM	Crew resource management (CRM) is a training initiative based on non-technical skills(interpersonal communication, leadership, and decision) , developed in light of many aviation incidents and accidents. The maritime equivalent of CRM is termed bridge resource management (BRM), or Bridge Team Management (BTM) (as opposed to Bridge Management Team (BMT) which is the crew), and has been used in the maritime industry for the last decade (Hetherington et al. 2006). The essence of BRM is the effective use of all available resources to complete an operation safely (TSB 1998). BRM depends on a free float of information covering any limitations on the operational status of the ships and the role that the individuals play. BRM intends to fully utilize all the assets, particularly the human assets on a ship's bridge, reducing the risk of a 'one person' accident. This means that every person on the bridge should know the passage plan, and the intentions of the navigating officer. BRM maximizes the involvement and contribution of the whole crew. Communication between the parties is essential in an effective BRM (ATSB 2002). If the officer in charge does not share his passage plan openly with the other crew members, or open communication is not the norm, the bridge is deemed to have an LTA BRM application.

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Variable	Description
LTA Procedures	The BMT may develop routines and norms which may not be the same or compatible with the company's guidelines, the BRM or rules and regulations. If an operation is routinely done in this way, for instance navigating without fixing the vessel's position, it is interpreted as LTA Procedures.
Language barriers	Accurate communication skills are important because of the many cultures and nationalities that work together (Manuel 2011; Macrae 2009). This can create language problems, and flag states therefore require that each ship must have a working language that each employee must speak to a certain standard. Lack of adequate language skills may create language barriers and can increase the stress level on board (Rothblum et al. 2002). Communication and hence an effective BRM are affected by language barriers. If the cooperating bridge crew has problems understanding each other, or a language is used which excludes other members of the bridge team, the bridge is deemed to have language barriers. Language barriers may, for instance, be created with foreign embarking pilots.
Alcohol	A particular hazardous situation is when circadian effects are coupled with alcohol and monotonous conditions; even low alcohol exposure significantly impairs the performance of maritime pilots (Howland et al. 2001). Alcohol and fatigue also have similar effects on human cognitive capacities. A period of sustained wakefulness of 18 hours can be comparable to a blood alcohol concentration (BAC) of 0,05%. If sleep deprivation continues for 24 hours, the effect of fatigue is equal to a BAC level of 0,10%. Use of alcohol also significantly impairs the ability to visual searching and the solving of navigational problems (Marsden and Leach 2000). Prolonged watches in combination with misuse of alcohol is a major cause of fatigue-related accidents (IMO 2001). The variable is used when at least one of the BMT is under the influence of alcohol at the time of the accident.

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Variable	Description
LTA Navigation	Faulty positioning of the vessel, navigating only by sight or wrong use of navigational equipment is defined as LTA Navigation.
Pilot involved	Pilots are mariners with detailed knowledge of local waters. They are used to guide ships through dangerous or congested waters. However, a pilot is not a member of the normal BMT and may thus disturb the communication, adapted procedures and the general attitude towards safety.
Experience	Experience is measured by the number of years the main officers involved in the accident had at sea.
Visual conditions	When the accident investigators deemed visibility to be restricted by the weather conditions it is defined as Visual conditions.
Stream /Current	When the maneuverability of the vessel is affected, or when the vessel drifts with stream or flood tides it is defined as Stream.
Monotonous conditions	Calm weather conditions coupled with no traffic in open waters and no other duties at the bridge are interpreted as monotonous conditions.
LTA Bridge design	If the accident investigators explicitly remark on the poor bridge design and ergonomic weaknesses this is interpreted as LTA Bridge design.

Concluded

3. Data

Different maritime organizations investigate accidents and log their findings in their databases. However, there is a lack of focus on human and organizational factors (HoFs) (Kristiansen 2001; Schröder-Hinrichs et al. 2011). Often, all kinds of human errors are grouped into one crude category. Attempts have been made to divide HoFs into different categories, such as the Marine Accident Investigation Branch (MAIB)'s study on bridge watch keeping (MAIB 2004). However, there is no agreed upon categorization of the various HoFs and their interconnectedness. The HoFs are all presented in one pie chart without separating the blunt-end (nearest management) factors with the sharp-end (at the scene) factors.

For these reasons, it is suggested that analyses of maritime accidents may reveal valuable information regarding the effect of HoFs on the risk of accidents (Celik and Cebi 2009). Various maritime accident investigation reports are available and they are often comprehensive enough for identifying and analysing HoFs. In other words, they provide a deeper insight into each accident than the databases do. As mentioned in Section 2, the data in this article is collected from 93 accident investigation reports on groundings investigated by agencies in Norway, Sweden, Canada, the United Kingdom and Australia was collected in the study (see Table 1). The accidents occurred in the time

Table 2. Reports from five accident investigation branches (Akhtar and Utne 2014)

Accidente investigation branch	Number of accidents
Norway – (AIBN– Accident Investigation Board Norway)	3
Sweden – (SHK– Swedish Accident Investigation Authority)	3
Canada – (TSB – Transportation Safety Board of Canada)	26
United Kingdom - (MAIB – Marine Accident Investigation Branch)	31
Australia – (ATSB – Australian Transport Safety Bureau)	30
Total	93

Source: The data collected from the accident investigation reports were also utilized in Akhtar and Utne (2014).

period 1997–2012 (mean year 2003). Older accidents are not included to minimize the effects of technological development and management changes.

An adequately manned BMT, for instance, for a medium-sized tanker is assumed to require one master, and minimum three bridge team members per shift. The master may be called for when needed. Assuming only two shift crews, a minimum of seven seamen are required for a well-functioning BMT. Vessels on a route with a shorter passage time of one day are excluded in the dataset, since it is assumed that long-distance passages have a different kind of fatigue associated with them than ships on short routes with frequent port visits. Likewise, supply vessels and leisure boat accidents are also excluded. Further on, grounding accidents with a major technical failure (for instance, engine failure or rudder failure) are excluded from the data set. Finally, accident investigation reports without analyses of organization and management at the time of the accident are rejected. Summing up, the criteria for including an accident investigation report in the study are:

1. Accident date between 1997–2012
2. Minimum seven crew members
3. Passages frequency ¿1 day
4. Not a supply vessel or leisure boat
5. Not a supply vessel or leisure boat
6. All main technology instruments and equipment must have been functioning at the time of the accident
7. The accident investigation report describes the organizational/management involvement

4. Analysis

Akhtar and Utne (2014) constructed a Bayesian Network (BN) including 63 fatigue influencing factors. LTA BRM and LTA Procedures were the two most often occurring fatigue-influencing factors in the accident investigation reports. They were present in 76% and 75% of the accident investigation reports, respectively. LTA Navigation and LTA Safety climate were also identified in 55% of the accident investigation reports. Fatigue was found to be present in 41% of the reports. Figure 2 shows the amount of times (in percentage) the various fatigue-influencing factors were identified in the accident investigation reports. However, simple frequency analysis is not sufficient to determine which of the fatigue-influencing factors have the strongest influence on fatigue. In Akhtar and Utne (2014), LTA Manning level was the most important fatigue influencing factor; it raised the probability of fatigue in the BMT by over 30%.

Several of the fatigue-influencing factors are relatively broadly defined. They may also to some extent overlap so that the same phenomenon may be explained by different fatigue-influencing factors. Multivariate regression analysis of the fatigue-influencing factors is helpful for identifying the overlapping fatigue influencing factors. Traditional statistical regression methods may be efficient (See Section 4.1) in finding the relationships between the various factors. They also do not require a predetermined structure or a mindset of the problem. The factors (which are termed variables in regression analysis) are all treated equally without any subjective interference by the researcher (unless there is multicollinearity between them, see Section 4.1.1).

4.1. Multivariate Analyses

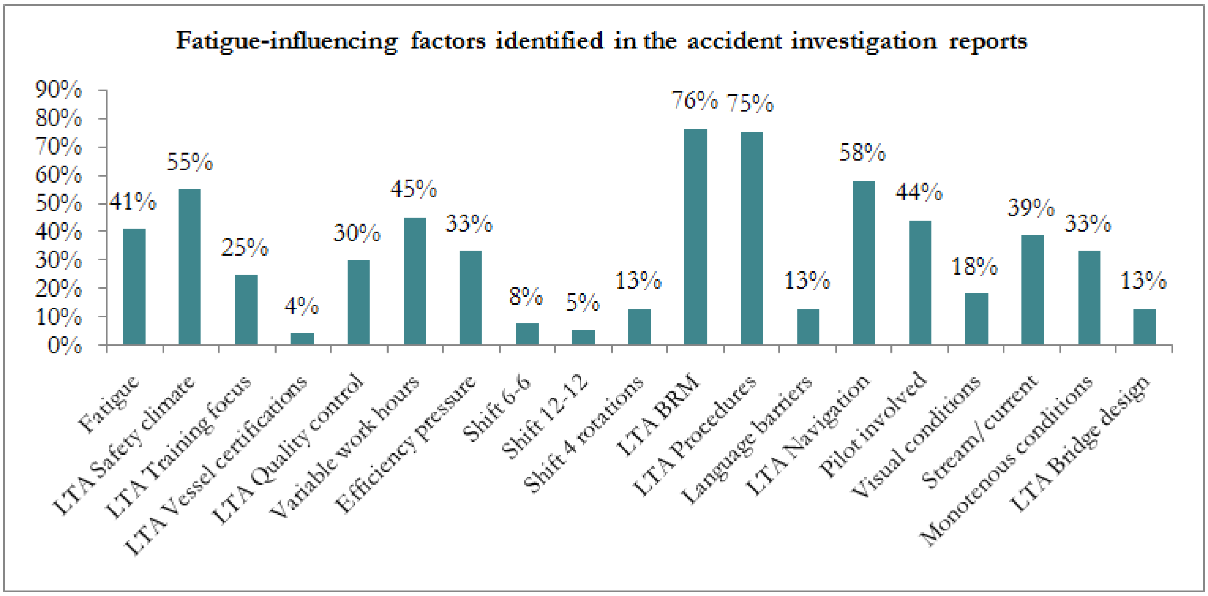
Regression analysis is a widely used statistical technique to explore the relationships between variables in a dataset. The technique can also produce mathematical models which can be used for prediction (Lipovetsky and Conklin 2000). The regression analysis plots the data in a concise way using a mathematical function. In this function, variables are used from the dataset. Some of the variables in the analysis turn out to be important for describing the dependent variable (significant effect on the regression plot), whereas others are of less importance. Hence, the analysis indicates the variables of importance, or which explain the phenomenon represented by the dependent variable. By this, new theories about connections between the dependent variables and multiple independent variables may be made or old theories may be tested (York 2012). In this article, the dependent variable (fatigue) is dichotomous (coded as 0 or 1), Logistic regression is therefore used to model the non-linear relationships between the fatigue influencing factors. For details about regression analysis, incl. logistic regression, the reader is referred to (SPSS 2009; Walpole et al. 1998; Pampel 2000).

If a multi-regression model has the proper controls, one may legitimately make a statement about the effects of X on Y, 'all else being equal' (York 2012). By introducing one variable at a time into the regression model, instead of all at once, one may assess the effects of the independent variables (Y) on the dependent variables (X). At the same time one has to control the effects of other variables which also may be correlated with the dependent variable. The article makes use of this technique.

4.1.1. Multicollinearity

The problem with multicollinearity is when two or more independent variables are highly correlated with another inde-

Figure 2: Number of times (in percentage) the fatigue-influencing factors were identified in the 93 accident investigation reports.



Source: Authors

pendent variable. In other words, the collinearity problem in a regression analysis is when one of the independent variables has a perfect linear relationship to one or more of the other independent variables. The more variables that are used in a model, the higher the effect of multicollinearity, because the predictors provide partially redundant information (Lipovetsky and Conklin 2000).

Near-collinearity is when the variables are highly correlated, but not perfectly. Spurious correlations may lead to near collinearity. In the case of near collinearity, the regression coefficients become unstable, or they increase strongly in size. Variables that are leading to near collinearity may then be excluded from the analysis. If two variables are correlating strongly, often neither of them are needed to analyse the phenomenon under examination (SPSS 2009). To avoid any spurious near collinearity, independent variables which have no conceivable relationship with the dependent variable may be excluded, especially if they disturb the regression coefficients. For instance, it is assumed that Alcohol does not have en direct effect on Manning level (dependent variable in Table 4). Inclusion of Alcohol also disturbs the regression coefficient by making their value unstable and unrealistically large. Alcohol is therefore not included in two of the regression analyses (Table 4 and Table 5).

The independent variables should be included in the analysis with care, and including them one by one discloses any collinearity problems. In this article, several regression models are made for the same dependent variable, increasing the number of independent variables for each model until all the variables are included.

Table 3 shows the results of the step-by-step regression analysis, where one variable at a time is introduced. For example, in the logistical model 1 (Table 3) LTA Manning and LTA Safety climate are the two variables describing Fatigue, whereas only LTA Manning is shown to have significant effect (relationship) with Fatigue. However, using our dataset to try to explain the variable Fatigue by only two independent variables does not produce models which explain the variations of the dependent variable (Fatigue) in our dataset. The low value of the coefficient Nagelkerke R2 is an indication of this (highest possible value is 1,0). However, the coefficient increases (the models explain the dependent variable better) as more independent variables are introduced.

PASW software version 18.0.1 is used in this study (SPSS 2009); in addition, the significance level for entering variables in the logistical regression method is set at 0,05 and for deletion at 0,10.

4.1.2. Fatigue as the dependent variable

In model 1 (Table 3), we see that only LTA Manning contribute significantly (by p- value 0, 99) to the probability (odds) of fatigue. In the Table the effect is labelled with three stars. Three stars signify p-value of 0,99, two stars 0,95 and one star 0,90. The higher the p-value, the higher the chance that the observation (the effect) is not a result of natural variations in the dataset, but rather a true effect (Walpole et al. 1998).

The interpretation of model 1 in Table 3 is that when the value of LTA Manning increases by one unit (i.e., goes from Adequate manning levels, to LTA Manning levels), the probability of Fatigue in the BMT increases by a factor of 7,1, i.e., the probability increases 7,1 times. The actual probabilities are not a subject of this paper, but can be found in Akhtar and Utne, 2014.

An increase in LTA Safety climate (from 0 to 1) is expected to increase the probability of Fatigue by 1,6. However, this variable does not contribute significantly in the analysis and one may therefore also disregard its effect on fatigue. In short, model 1 indicates that controlled for safety climate, manning levels significantly have an effect on fatigue in the BMT.

In model 5, Variable working hours is introduced. This contributes strongly to the probability of Fatigue (it increases it by a factor of 23,7) controlled for the other variables in the model. Note also that LTA Safety climate now has a significant effect by p-value 0,90 on Fatigue, i.e., when Variable working hours is taken into consideration, safety climate becomes an important factor to explain the phenomenon of fatigue. However, its effect is not strong compared to the two other variables (LTA Manning and Variable working hours).

In model 6, we note that when Efficiency pressure is introduced, the effect of Variable working hours is almost doubled (increased from 23,7 to 40,1). This shows that a combination of the variables Efficiency pressure and Variable working hours is detrimental to the fatigue levels on board a ship.

The effects of shift schemes on the probability of Fatigue alternate from being significant to non- significant. Note that Shift 6–6 first appears in model 7, however, its effect does not become significant until model 14, where Wrong navigation is introduced. It then stays significant until model 19, when Monotonous conditions is introduced and Shift scheme 12–12's effect is elevated to 146,8. This can be interpreted as Shift 6–6 having the strongest effect on fatigue compared to Shift scheme 12–12 and other schemes involving four rotations. In monotonous conditions, long shifts (Shifts 12–12) have the most wearing effect on the crew. However, because of the unstableness and a sudden increase of Shift 12–12 in model 19, and its effect being out of proportion in relation to the other work schemes, it is assumed that 12–12 has a collinearity problem with Monotonous conditions. Shift 12–12 is therefore not included as having a significant effect on the probability of Fatigue.

Language barriers have a weak significant effect in model 19 and 20. Alcohol does not have an effect on the probability of Fatigue. This may seem surprising; however, from earlier studies (Marsden and Leach 2000; Cuculic et al. 2009; Howland et al. 2001; Akhtar and Utne 2014) it is shown that alcohol leads to similar consequences as fatigue (wrong navigation, poor situational awareness etc), but there is not necessarily a correlation between alcohol and fatigue, i.e., a fatigued officer is not at more risk of misusing alcohol on duty than a non-fatigued officer or the other way around.

Wrong navigation does not seem to have a strong effect on the probability of Fatigue, nor do Experience, Visual conditions or Stream/current. However, Pilot involved significantly increases the probability of Fatigue. A reason might be that having a pilot onboard, which is not normally a member of the BMT, introduces new organisational, cultural and language challenges.

Monotonous conditions is an important variable. When introduced into the regression model, the effect of LTA Manning increases. The same occurs with the Variable working hours and Shift 12–12. In model 20, where LTA Bridge design is introduced, the effects of Monotonous conditions is somewhat increased. In other words, it is fatiguing to have LTA Bridge design when coupled with Monotonous conditions.

Only significant variables with a factor stronger than 1 are considered for further investigations. In conclusion, we note that for explaining the probability of Fatigue, the following variables in our database are the most important: LTA Manning, Variable working hours, Pilot involved and Monotonous conditions. In the following subsections, separate stepwise logistic regression analyses are conducted for these variables.

4.1.3. LTA Manning as the dependent variable

In the stepwise analysis in Table 4, LTA Manning is held as the dependent variable. Alcohol is not included in the analysis due to multicollinearity. An increase in the first five variables (LTA Safety climate, LTA Training focus, LTA Vessel certification, LTA Quality control and Variable working hours) does not have a significant effect on the probability of LTA Manning. LTA Quality control has a significant effect, until model 13 where Pilot involved is introduced. Pilot involved has a weak but positive effect on the probability of LTA Manning on the bridge.

An increase in Efficiency pressure leads to an increase in the probability of LTA Manning, with a factor of 35,2 in model 18.

However, only LTA BRM application and Efficiency pressure have a significant effect. The rest of the variables, including the three shift schemes, have no significant effect.

4.1.4. Variable working hours as the dependent variable

In Table 5, Variable working hours is the dependent variable. LTA Safety climate and LTA Training focus has a weak effect on the probability of Variable working hours. Efficiency pressure, Shift 12–12 and shifts with four rotations have a relatively strong effect. Interestingly, Shift 6–6 does not increase the probability of Variable working hours, while Shift 12-12 and Efficiency pressure do increase the probability. Shift 12–12 increases the probability of Variable working hours with a factor of 24,7, while the shift of four rotations does with a factor of 6,9. LTA BRM application also has a negative effect on Variable working hours, however it only comes into effect when LTA Bridge design is considered (model 17).

4.1.5. Pilot involved as the dependent variable

In Table 6, Pilot involved is the dependent variable. Only an increase in Language barriers increases the probability of having a pilot involved in the voyage. The interpretation of this relationship is that having a new member introduced in the BMT increases the probability of language barriers. This is true for many pilots, as they are especially called for by foreign vessel, i.e., often foreign vessels which are unfamiliar or uncertified for the specific waters have pilots on board. The results are therefore not surprising, as carrying a pilot on board is highly regulated, and therefore the other variables should not have any influence on its probability.

4.1.6. Variable Monotonous conditions as the dependent variable

Finally, in Table 7 Monotonous conditions, which also has a relatively strong influence on Fatigue (Table 3) is the dependent variable. We see that LTA Safety climate has an influence on Monotonous conditions, until the LTA BRM application is introduced, where it loses its influence. The interpretation is that when controlled for the LTA BRM application, LTA Safety climate does not have a significant influence on Monotonous conditions. Or in other words, adequate Safety climate is important for a adequate BRM application on board.

LTA Training focus has a small influence, until model 10, where it could no longer make itself manifest, as more variables are introduced. LTA Quality control has a significant and strong influence on Monotonous conditions, and so does LTA procedures.

Wrong navigation also has a small significant influence on Monotonous conditions, however the causal relationships are almost certainly the other way around, i.e., that an increase in Monotonous conditions is expected to yield an increase in the probability of Wrong navigation.

5. Results

Figure 3 combines the results from all of the regression analyses in the present study. The Figure may also be seen as a hierarchical model of the strongest fatigue influencing factors in maritime transport. In short, Figure 3 shows that Fatigue is most strongly influenced by LTA Manning, Variable working conditions, Pilot involved and Monotonous condition. Out of these four, LTA Manning and Variable working conditions are the most important variables. LTA Manning increases the probability of fatigue in the BMT by a factor of 109, while Variable working conditions increases it by a factor of 45. Further on in Figure 3, the four main fatigue-influencing factors or variables are linked with those factors influencing them the most.

Straight lines are used in Figure 3, instead of arrows, to emphasize that regression analyses do not automatically yield any information about causality. Still, it is plausible to believe that all four variables to which Fatigue is linked to in Figure 3 cause fatigue, and not the other way around. It is, for instance, difficult to imagine how a fatigued officer would bring about Monotonous conditions for the shift. However, there are several other connections where deciding on causality that may not be straightforward, for instance, the link between LTA Manning and Efficiency pressure, or Variable working conditions and Shift 12–12.

Efficiency pressure is strongly linked with LTA Manning and Variable working conditions, both of which are the two main fatigue variables. A Shift scheme with 4 shifts per 24 hours has an effect on Variable working conditions, but not as much as Shift 12–12. Officers working 12–12 have a significantly higher probability of having to work at hours which are not planned for, which in turn has an impact on their fatigue levels. The LTA BRM application is linked with LTA Manning and Variable working conditions. Most likely, LTA Manning and Variable working conditions impact the LTA BRM application. However, the LTA BRM application is not statistically significant in the regression model with Fatigue as the dependent variable. Language barriers is the only variable which is linked to Pilot involved. This may mean that culture differences and different languages between the crew and the pilot is fatiguing for the crew. LTA Quality control and LTA Procedures are linked to Monotonous conditions. Again, it is plausible to believe that the two latter variables impact the former variable. For instance, poor procedures may lead to low frequency of rotation of duties when the ship experiences monotonous conditions.

6. Conclusions

The results show that less than adequate (LTA) Manning has the strongest influence on fatigue levels in a BMT on board a ship. Manning also influences other important variables, such as Efficiency pressure and LTA BRM. It is crucial to have sufficient manning so that the crew is able to conduct their job without high levels of fatigue. With regards to fatigue, a shift scheme with four rotations per 24 hours seems to be preferable to 12 hours on and 12 hours off. Five variables stand out among the others; namely LTA Manning, Variable working conditions, Efficiency pressure, Shift 12–12, and LTA BRM application.

In general, the regression analyses do not show causality; rather they only indicate the influence various variables have on each other. Conducting regression analyses step by step, by introducing one independent variable at a time gives a valuable insight to the end regression model. It highlights the most important variables (fatigue influencing factors) that influence the dependent variable. It is also easier to recognize variables which covariate and hence, if necessary, omit them.

Regression analysis is useful for estimating relationships among variables, especially when the number of variables is high. It also allows for assessing the effect the various variables have on the dependent variable, such as Fatigue. By constructing the relationships between the variables (construction models), prediction may be done. The construct of the models does not require any predetermined taxonomy, which ensures a relatively objective analysis. Still, the data used in the present study are to some extent based on subjective interpretation of the fatigue influencing factors coded from accident investigation reports. This has to be taken into consideration when assessing possible sources to uncertainties in the results.

Bayesian Networks, as in Akhtar and Utne (2014), may be useful to get an overview of the system, and to find which factors most strongly influence, for instance, fatigue. However, it is still difficult to understand the interplay between the factors, which the present study focuses on. The construction of the BN also requires a predetermined structure or taxonomy.

The results in this article should be generalized with care. The sample of accident investigation reports in the study is for ships containing a minimum of seven crew members on long voyages. Furthermore, it should be kept in mind that the sample size of this study is 93 and the accident type is ship groundings. Although the sample size is large enough to conduct statistical regression analysis, a worldwide maritime database containing human and organization factors (HoFs), similar, but larger than the one in this study would have been desirable. The study in this article only focuses on variables which influence fatigue in the BMTon board ships. Further research should also include

Table 3. Logistic regression with Fatigue as the dependent variable ($*p < 0,10 ** p < 0,05 ***p < 0,01$)

\ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
LTA Manning	7.1***	6.7***	6.0**	6.9**	5.8*	10.9 **	7.9*	6.7*	8.2*	10.1 **	8.5*	8.7*	19.9 **	13.2	97.4 **	100.6 **	93.4 **	90.8 **	132.3**	109.1*
LTA Safety climate	1.6	1.8	1.2	1.8	2.9*	4.1*	3.7*	4.0**	3.6*	3.0	2.5	2.7	2.6	3.0	2.7	2.9	3.0	3.1	3.1	3.1
LTA Training focus		0.5	0.4	0.4	1.4	1.2	1.2	1.2	1.0	1.1	1.0	1.1	2.2	2.1	2.3	2.2	2.2	2.2	3.8	3.7
LTA Vessel certification			4.3	4.3	0.7	1.3	1.4	1.4	1.8	3.7	3.9	5.2	0.4	0.8	0.8	0.9	0.9	1.0	0.2	0.3
LTA Quality control				1.0	0.6	0.5	0.5	0.4	0.4	0.3	0.3	0.3	0.1*	0.1	0.2	0.2	0.2	0.2	0.1	0.1*
Variable working hours					23.7 ***	40.1 ***	37.6 ***	34.8 ***	31.6 ***	29.9 ***	30.8 ***	33.1 ***	18.4 ***	18.7 ***	35.0 ***	35.4 ***	35.7 ***	37.6 ***	42.0 ***	44.8 ***
Efficiency pressure						0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.2	0.2
Shift 6-6							7.3	8.2	8.9	11.9	14.4	16.9	17.2	21.1*	100.8 **	84.9 **	84.1 **	81.6 **	37.5	37.1
Shift 12-12								4.4	5.0	6.1	6.8	8.1	12.2	12.0	39.2*	43.5*	39.8	37.3	146.8*	168.0*
Shift 4 rotations									2.6	3.5	3.0	3.2	4.8	5.4	15.0*	15.6*	15.0	16.7	6.5	7.0
LTRA BRM application										2.8	2.7	2.5	2.4	3.1	3.0	3.0	2.9	3.0	1.9	1.9
LTA Procedures											2.0	1.9	1.1	1.8	2.5	2.5	2.4	2.3	1.0	1.1
Language barriers												0.51	2.84	0.30	0.04	0.04	0.04	0.04	0.2*	0.0*
Alcohol													0.83	0.38	0.21	0.24	0.24	0.23	0.549	0.561
Wrong navigation														0.3	0.2*	0.2*	0.2*	0.2*	0.3	0.2
Pilot involved															9.7**	9.8**	9.6*	9.7**	11.9**	11.9**
Experience																1.0	1.0	1.0	1.0	1.0
Visual condition																	1.1	1.1	1.4	1.4
Stream or current																		0.9	1.4	1.5
Monotonous conditions																			12.7**	13.2**
LTA Bridge design																				1.4
Nagelkarke R^2	0.13	0.15	0.17	0.17	0.52	0.54	0.56	0.56	0.57	0.59	0.59	0.60	0.51	0.54	0.61	0.61	0.61	0.61	0.67	0.67

Table 4. Logistic regressions with LTA Manning as the dependent variable. Alcohol is not included in the model. ($*p < 0,10$ $**p < 0,05$ $***p < 0,01$)

\ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
LTA Safety climate	2.4	2.5	1.6	1.7	0.9	0.8	0.8	0.9	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.5
LTA Training focus	1.7	1.5	0.9	1.2	2.1	2.3	2.2	2.4	2.3	2.3	2.4	2.3	1.9	1.9	2.1	2.5	2.1	2.0
LTA Vessel certification		2.6	1.7	1.1	0.3	0.4	0.3	0.3	0.6	0.6	0.6	0.6	0.3	0.3	0.4	0.3	0.2	0.2
LTA Quality control			5.4***	4.9***	6.2***	5.6**	5.5**	5.5**	5.8**	3.9*	3.9*	3.9*	3.4	3.2	2.8	2.7	3.0	3.0
Variable working hours				1.8	0.7	0.6	0.6	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.7	0.7
Efficiency pressure					11.3***	13.1***	13.0***	10.8***	21.12***	19.0***	18.9***	17.6***	22***	21.8***	31***	33.3***	34.8***	35.2***
Shift 6-6						4.9	5.0	4.3	4.9	4.5	4.5	4.2	2.9	2.8	2.3	2.4	0.3	2.9
Shift 12-12							1.3	1.1	0.7	0.7	0.6	0.7	0.7	0.6	0.8	0.5	0.4	0.4
Shift 4 rotations								0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
LTRA BRM application									9.5**	7.2**	7.2*	8.6*	16**	16.6**	27.5**	20.9**	21.9**	21.8**
LTA Procedures										5.0	5.0	5.3	4.6	4.8	5.0	5.4	7.4	7.4
Language barriers											0.9	0.80	1.60	1.70	1.80	2.50	2.70	2.70
Wrong navigation												0.6	0.6	0.6	0.6	0.7	0.7	0.6
Pilot involved													0.3*	0.3*	0.2*	0.2*	0.2*	0.2*
Experience														1	1	1.0	1.0	1.0
Visual condition															0.3	0.2	0.2	0.2
Stream or current																0.4	0.4	0.4
Monotonous conditions																	0.4	0.4
LTA Bridge design																		1.4
Nagelkarke R^2	0.06	0.07	0.20	0.22	0.37	0.40	0.40	0.42	0.48	0.51	0.51	0.51	0.55	0.55	0.57	0.58	0.59	0.59

Table 5. Logistic regressions with Variable working hours as the dependent variable. LTA Vessel certification, Monotonous conditions, Stream and current, Alcohol are excluded. ($*p < 0,10 ** p < 0,05 ***p < 0,01$)

\ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LTA Manning	1.9	2.3	2.1	1.8	0.7	0.6	0.7	0.8	0.7	0.7	0.7	1.6	0.63	0.6	0.6	0.6	0.6
LTA Safety climate	0.7	0.9	0.9	0.7	0.5	0.4	0.5	0.3*	0.2**	0.2**	0.2**	0.2*	0.2**	0.2**	0.2**	0.2**	0.2**
LTA Training focus		0.3**	0.2***	0.2*	0.3*	0.3	0.2*	0.2**	0.2*	0.2*	0.2*	0.23**	0.2**	0.2**	0.2**	0.2**	0.2*
LTA Quality control				2.5	2.8	2.6	2.6	2.1	1.9	1.8	1.8	9.9	1.7	1.6	1.6	1.7	1.6
Efficiency pressure					9.7***	10.6***	11***	13.6***	19.5***	20.8***	22.0***	24.8***	20.1***	20.8***	21.3***	21.4***	24.1***
Shift 6-6						3.5	3.9	2.7	4.2	4.3	4.3	1.9	3.8	3.7	3.3	3.4	4.9
Shift 12-12							15*	23***	22.9**	23.3**	23.6**	10.5	28.2**	27.1**	29.2**	28.7**	24.7**
Shift 4 rotations								5.3*	6.6**	6.4**	6**	2.4	6.7**	6.6**	6.3**	6.5**	6.9**
LTRA BRM application									2.7	2.6	2.8	2.8	3.3	3.4	3.4	3.4	4.3*
LTA Procedures										1.4	1.4	0.8	1.7	1.7	1.7	1.8	1.8
Language barriers											1.6	2.00	1.60	1.70	1.70	1.70	1.90
Wrong navigation													0.5	0.5	0.5	0.5	0.5
Pilot involved														0.9	0.8	0.8	0.9
Experience															1	1.0	1.0
Monotonous conditions																0.9	0.8
LTA Bridge design																	0.4
Nagelkarke R^2	0.03	0.10	0.23	0.14	0.34	0.36	0.40	0.44	0.46	0.46	0.47	0.47	0.48	0.48	0.48	0.48	0.49

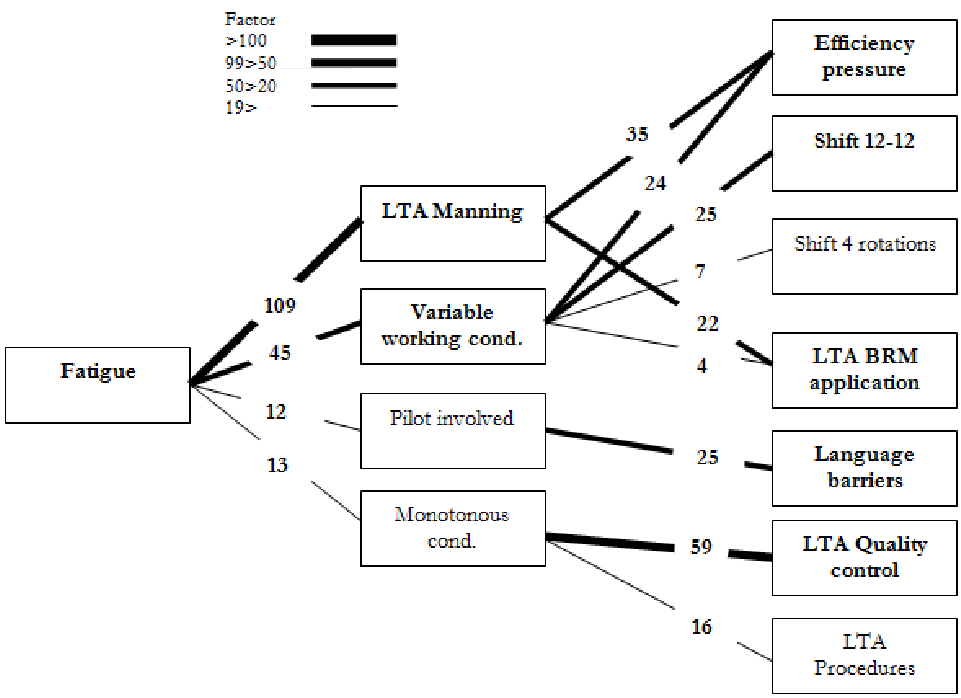
Table 6. Logistic regressions with Pilot involved as the dependent variable. ($*p < 0,10$ $**\ p < 0,05$ $***p < 0,01$)

\ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LTA Manning	0.4*	0.4*	0.4*	0.5	0.5	0.4	0.5	0.5	0.4	0.3*	0.3*	0.3*	0.4	0.4	0.4	0.4	0.4	0.4	0.4
LTA Safety climate	0.7	0.8	0.8	0.9	0.9	0.8	0.9	0.9	1	0.8	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
LTA Training focus		0.4*	0.4	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.3*	2.7	3.1	3.0	3.0	3.2	3.0	2.7
LTA Vessel certification			0.7	0.8	0.9	0.8	0.7	0.7	0.5	0.8	0.8	0.4	1.1	0.6	0.7	0.7	0.5	0.6	0.7
LTA Quality control				0.6	0.7	0.7	0.7	0.7	0.8	0.7	0.7	0.7	0.1**	0.1**	0.1*	0.1*	0.1*	0.1*	0.1*
Variable working hours					0.9	0.8	0.9	0.9	1.1	0.9	0.9	0.9	1.5	1.6	1.5	1.6	1.4	1.4	1.5
Efficiency pressure						1.3	1.2	1.2	1.2	1.5	1.5	2.0	1.9	2.2	2.1	2.0	2.3	2.2	2.0
Shift 6-6							0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.4	0.4	0.4
Shift 12-12								1.5	1.2	1.3	1.3	0.9	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Shift 4 rotations									0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
LTRA BRM application										2.5	2.5	3.3*	2.3	2.1	2.1	2.1	2.1	2.2	2.1
LTA Procedures											0.9	0.8	1.1	0.9	0.8	0.8	0.8	0.9	0.9
Language barriers												8**	34.5**	32.9**	30.8**	31.1**	28.9**	29.8**	24.6*
Alcohol													0.50	0.80	0.90	0.80	1.00	0.90	0.9
Wrong navigation														2.1	2.1	2.2	2.4	2.3	2.0
Experience															1	1.0	1.0	1.0	1.0
Visual condition																1.1	1.2	1.2	1.2
Stream or current																	1.6	1.5	1.6
Monotonous conditions																		0.8	0.8
LTA Bridge design																			1.9
Nagelkarke R^2	0.07	0.11	0.11	0.12	0.12	0.12	0.15	0.15	0.18	0.20	0.20	0.28	0.31	0.33	0.33	0.33	0.34	0.34	0.35

Table 7. Logistic regressions with Monotonous conditions as the dependent variable. ($*p < 0,10$ $**p < 0,05$ $***p < 0,01$)

\ Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
LTA Manning	1.5	1.6	1.6	0.9	0.9	0.8	0.7	0.7	0.8	0.7	0.6	0.6	0.3	0.3	0.3	0.3	0.2	0.2	0.2
LTA Safety climate	4.3**	4.9***	4.9***	4.2**	4.6**	4.5**	4.2**	4**	3.5*	3.0	2.4	2.4	2.9	3.2	3.2	2.8	2.4	3.2	3.3
LTA Training focus		0.5	0.5	0.2**	0.3*	0.3*	0.3*	0.3	0.3*	0.3*	0.3*	0.3	0.9	0.7	0.7	0.9	0.1	0.5	0.5
LTA Vessel certification			0.8	0.6	0.4	0.4	0.5	0.5	0.7	0.9	0.9	0.8	15.7	42.5	44.9	33.0	25.9	80.6	85.0
LTA Quality control				6.7***	6.2***	6.3***	6.2***	6.3***	6.1***	5.6**	4.6**	4.6**	20.6**	31.2*	28.5*	21.2	18.4	56.1*	59*
Variable working hours					1.6	1.6	1.4	1.4	1.2	1.1	1.1	1.1	1.6	1.6	1.6	1.7	1.6	2	2
Efficiency pressure						1.0	1.2	1.2	1.2	1.6	1.8	1.8	0.5	0.4	0.5	0.7	0.8	0.6	0.6
Shift 6-6							3.6	3.5	3.4	3.6	3.9	3.9	15.5	9	8.7	14.5	15.1	8.4	9.8
Shift 12-12								0.6	0.7	0.6	0.6	0.5	0.2	0.2	0.1	0.1	0.2	0.6	0.6
Shift 4 rotations									2.6	3.3	2.6	2.6	12.7	13.8	12.7	8.4	9.9	11.7	11.5
LTRA BRM application										2.5	2.2	2.2	2.5	2.9	3.3	3.4	3.7	2.3	2.3
LTA Procedures											3.2	3.2	4.5	8.9	9**	10.8**	11.7**	15.8**	16.3**
Language barriers												1.10	1.60	1.90	2.20	2.80	2.60	2.70	2.7
Alcohol													1.10	0.30	0.30	0.20	0.20	0.90	0.1
Wrong navigation														0.2*	0.2*	0.2*	0.2*	0.2**	0.2**
Pilot involved															0.7	0.6	0.7	0.7	0.8
Experience																1.0	1.0	1.0	1.0
Visual condition																	0.6	0.5	0.5
Stream or current																		0.2*	0.2*
LTA Bridge design																			0,6
Nagelkarke R^2	0,12	0,15	0,15	0,28	0,29	0,29	0,31	0,31	0,33	0,34	0,37	0,37	0,51	0,56	0,56	0,57	0,58	0,62	0,62

Figure 3: Hierarchical model of fatigue



possible consequences of fatigue (for instance memory problems, lowered reaction time and grounding). This would help to determine the effect of fatigue on, for example, the probability of ship grounding. Conducting cost- benefit analysis for fatigue mitigating measures would also be more accurate when links to consequences are established and quantified.

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