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Human Factor Modelling in the Risk Assessment of Port Manoeuvers

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ABSTRACT: The documentation of human factor influence on the scenario development in maritime accidents compared with expert methods is commonly used as a basis in the process of setting up safety regulations and instructions. The new accidents and near misses show the necessity for further studies in determining the human factor influence on both risk acceptance criteria and development of risk control options for the manoeuvers in restricted waters. The paper presents the model of human error probability proposed for the assessment of ship masters and marine pilots' error decision and its influence on the risk of port manoeuvres.

1 INTRODUCTION

The introduction of the Convention on the Standards of Training, Certification and Watchkeeping 1978, as amended 1995 (STCW95) and the International Safety Management (ISM) Code, implemented through Flag State Implementation (FSI) or Port State Control (PSC) has much increased safety standards related to the personnel performance in maritime shipping. Safety Management System can be improved by identifying human factors and analyzing human interactions (Einarsson, and Brynjarsson, 2008). New accidents show that there is still a room for development of human factor, mainly with respect to fatigue and stress (Berg, 2013; Fahlgren, 2007; Hejmilch, 2015; Hetherington, 2006; Mokhtari & Khodadadi Didani, 2013).

According to The Institute of Ergonomics and Human Factors (UK) the definition for human factor is formulated as follows: "Ergonomics (or Human Factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance." Encyclopaedia Britannica says: "Human-factors engineering also called ergonomics or human engineering science is dealing with the application of information on physical and psychological characteristics to the design of devices and systems for human use. The term human-factors engineering is used to designate equally a body of knowledge, a process and profession. As a body of knowledge, human-factors engineering is a collection of data and principles about human characteristics, capabilities and limitations in relation to machines, jobs and environment".

There are three categories of human factors specified in anthropotechnical systems:

- individual factors (Reason, 1998):
  - competence level,
  - stress,
  - motivation,
- group factors:
  - management weaknesses,
  - supervision and crew factors,

- organizational factors,
  - company policies,
  - company standards,
  - systems and procedures.

The International Maritime Organization (IMO) has considered the human factor as the reason of 80% of all maritime accidents mostly concentrated on two areas:
- negligence - 30% of marine accidents,
- not adequate knowledge and practice - 20% of marine accidents.

Personal characteristics of people involved in events clearly implicate causal factors relating to the workplace and system (Reason, 1998).

The comprehensive study on human and organisational factors in ship collisions, presented by Chauvin et al., (2013) stresses the necessity to investigate the masters' decisions in critical conditions concerning mainly bridge manning and vessel speed. These decisions are related to SMS, ISM and company safety culture.

The efficiency of the ISM is also put into question (Battacharya, 2012) as it is understood by ship masters mainly as a managerial tool and undermines professional skills of seafarers leading to its rejection.

Ship masters responsible for the ship operations at the same time can have personal problems affecting their behaviour. This creates a more stressful environment for a man supposed to be fit for 24 hours duty. Lots of paper work imposed on the ship staff does not make situation any batter. Company budget holders seek to minimize the manpower costs reducing the crew number on board. Stresses accumulate and they influence the probability of seafarers' mistakes and wrong decisions. The main objective of the study presented in the paper is to find out how does the stress influence the decision making process and consequently the human error during ship manoeuvring in restricted area.

2 HUMAN ERROR ASSESSMENT

Main data for the assessment of human error in maritime shipping is the information available in past accident investigation reports. Transport Safety Board (TSB) of Canada and Marine Accident Investigation Branch (MAIB) of the UK take human and organisational factors into account using their own investigative methodologies.

The full text of 44 Incident at Sea Reports was coded and analysed using NUDIST software by Philips (2000). This sample includes collisions and groundings reported since 1991, where significant human factors were contributed to the incident. The Incident at Sea Reports was electronically searched for reference to sleep and content was indexed against parameters such as fatigue behaviours, time of day and contributing personnel. Incident at Sea Reports incorporate three levels of reference to sleep, analysis of which may associate sleeping and sleepiness with accident causation. The highest level of reference associates being asleep or being sleep deprived with accidents, but not always with fatigue.

Chauvin et al. (2013) presented the Human Factor Analysis and Classification System designed for human factors accident investigation and analysis of the underlying causes of human error. The HFACS has been developed on the basis of previous studies and applications used in military and civil aviation, in the railway and mining industries for the classification and analysis of accident data, in shipping industry for the investigation of maritime accidents and mishaps (Chauvin et al., 2013). HFACS system describes human error at four levels of failure:
- unsafe acts of operators,
- preconditions for unsafe acts,
- unsafe supervision,
- organizational influences.

With respect to ship collisions the unsafe acts related to decision-making concern 85% of the vessels involved in the investigated 27 collisions. The main reasons of collisions in restricted waters involving licensed pilots were inter-ship communication problems and BRM (Bridge Resources Management) deficiencies (Chauvin et al., 2013).

The limitation of the studies based on investigation reports is to small number of cases in comparison to the number of variables, which does not support the stochastic modelling. It is also very difficult to investigate the influence of ship masters and marine pilots personality characteristics on their attitudes towards risk and probability of error in decision making process due to the lack of evidence.

The influence of the stressing factors on the decision making process is important in risk assessment of accidents related to the navigation in restricted waters and this can be studied mainly using expert methods. To identify the personality characteristic and stressors ranking, the psychological questionnaires, followed by statistical analysis can be used.

2.1 *Personality characteristics*

Stressor is the appropriately ranked collection of stressing factors. Every stressor creates stress and brings up the risk of error making (Makarowski, 2008). Human personality characteristics called "Big Five Personality Traits" are the catalysts for the stress development. The five personality traits are as follows:
- openness,
- extraversion,
- conscientiousness,
- neuroticism,
- agreeableness.

The determination of error decision probability allows predicting the risk of wrong manoeuvre performance. With respect to the definition adopted by EMSA (Report, 2014), given by ISO 1999, risk is defined as a product of the probability of occurrence of harm and the severity of that harm.

The simplified model of the influence of human factor, related to personality characteristic of the ship master or marine pilot on the probability of error decision, risk of wrong manoeuvre performance and number of errors is presented in figure 1.

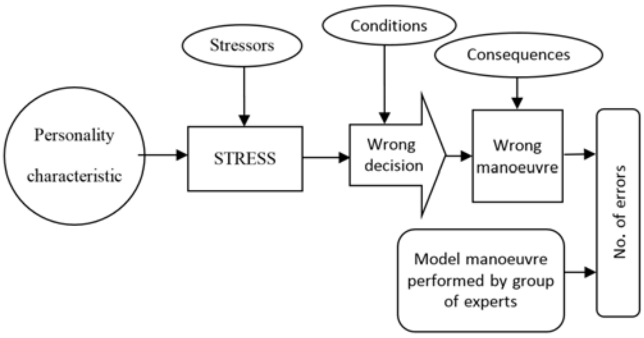

Figure 1 Simplified model of the influence of human factor related to personality characteristic of the ship master or marine pilot on the probability of error manoeuvre

The identification of the stressing factors should be based on the wide study on ship masters and marine pilots psychological characteristics followed by the practical tests on ship handling simulator. The results will be useful for the determination of weights which can be attributed to the experts performing navigational analyses or to determine the main stressors influencing the decision making process of the ship master on board, assessment of risk acceptance levels and development of ISM code.

2.2 *Stress as a predictor of failure*

Increased levels of stress (Hancock and Szalma, 2008; Sneddon et al, 2012) can result in:
- reduced working memory capacity,
- diminished attention,
- poor concentration/alertness,
- lower primary perception of the situation,
- inattention to the available information,
- narrowing of the individual’s attentional field,
- incorporation of only a restricted number of core aspects.

The levels of occupational stress (Mearns and Hope, 2005) and associations between stress and accident rates at sea have been measured in offshore industry (Sutherland and Cooper, 1986, 1996; Sneddon et al., 2012). The results of a mediation test showed that 48% of the relationship between stress and unsafe behaviour was mediated by work situation awareness (Sneddon et al., 2012).

The stress and fatigue were correlated but the multiple regression analysis showed that stress was the only significant predictor of situation awareness. Stress was found to be the only significant predictor for:
- concentration,
- projection,
- attention
- distraction.

The fourth examined variable was distraction. The significant predictor for distraction was the sleep disruption. Distraction can affect all the stages of perception, comprehension and anticipation therefore these distractive items were clustered into a single factor.

The principal components analysis of the situation awareness scale produced finally a four-factor model of the previously mentioned variables (Sneddon et al., 2012):

For the Work Cognitive Failures Scale (Broadbent et al., 1982; Wallace and Chen, 2005) a three-factor model has been identified using confirmatory factor analysis:
- memory,
- attention,
- action.

3 ASSESSMENT OF PORT MANOEUVRES DIFFICULTY

There are several phenomena which should be considered in the risk assessment of error during manoeuvring in restricted waters (Abramowicz-Gerigk&Burciu, 2012; Abramowicz-Gerigk&Burciu; 2014, Gerigk, 2012; Inoue, 2013). Full Mission Ship Handling Simulator is a tool which allows for the determination of risk indices and arrangement of repetitive test conditions. The risk indices are the limiting values of three dimensional safe manoeuvring space, ship motion parameters, ship propulsion and steering devices setting and output parameters in space and time domain (Hejmlich, 2014).

The model manoeuvre prepared on the simulator by the competent expert team can be used for the assessment of the manoeuvre performed by the examined ship master. Comparing the errors in dependence on human factor, allows concluding the human factor (in the meaning of stress) influence on the error probability and defining the acceptable risk for the particular manoeuvre in restricted area.

The example of a model manoeuvre and risk indices determined using Full Mission Ship Handling Simulator are presented in figures 2 and 3. The assumed deviation of a particular device setting is considered as an error in manoeuvre performance. Five points of highest risk have been defined in the examined area of Port of Gdynia.

To identify the attitudes of the examined pilots a simple questionnaire to be filled out before and after the test manoeuvre performed on ship handling simulator had been proposed. The pilots were asked to assess the difficulty of the test manoeuvre. An example of the questionnaire is presented in figure 4. The three independent variables influencing the manoeuvre performance were taken into account: knowledge of port area and experience - number of years of employment as a ship master and number of years of employment as a pilot.

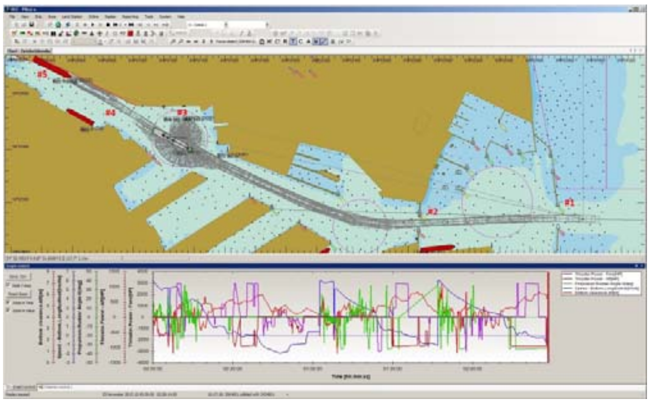

Figure 2. Example of a model manoeuvre: propulsion and steering devices parameters, ship speed and bottom clearance in time domain

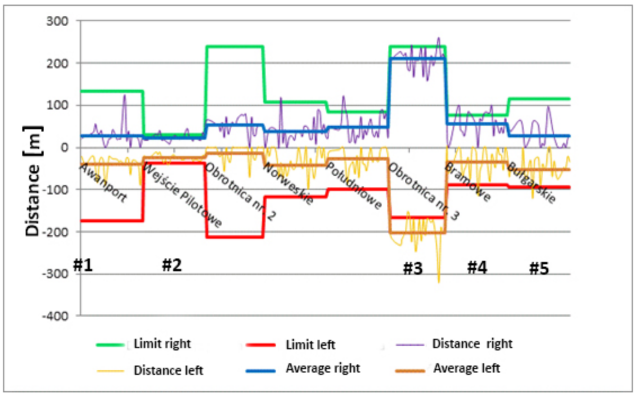

Figure 3. Example of the manoeuvre performance by examined pilots - geometrical boundaries - distances from center line of port canal

The preliminary set of three groups of pilots' attitudes towards risk had been identified:
- chancer, eager to take a risk,
- neutral, conservative,
- passive, reluctant to take a risk.

Knowledge of area 0= no, 1 = yes	Experience Captain years	Experience Pilot years	Time of manoeuvre min	Correctness of performance Scale 10-01 10 for no error, -1 for each error
0	4	15	112	10
0				
0				
0				
0				
0	10	4	112	10
0				
0				
0				
0				

	DANA-C Planning at point #	Scale 01-10 01 = easy, 10 = not performable degree of difficultness	Performance at point #	Scale 01-10 01 = easy, 10 = not performable degree of difficultness
1	#1	2	#1	3
	#2	3	#2	4
	#3	7	#3	5
	#4	5	#4	2
	#5	5	#5	2
2	#1	2	#1	3
	#2	4	#2	4
	#3	7	#3	6
	#4	7	#4	6
	#5	6	#5	5

Figure 4. Example of a questionnaire for port pilots performing manoeuvre on ship handling simulator

There were not clear dependencies observed between the examined variables on the tested group of 17 pilots. The conclusion was therefore to continue the research using bigger group of experts and prepare the questionnaires to determine their psychological characteristic and the degree of stress impacting the probability of error decision.

The ever-present hazards associated with ship master activity are called universals. They are included in one of the three groups of elements recognised in every recurrent accident scenario (Reason, 1998):
- universals,
- local traps,
- drivers.

In the maritime transport the universals include (Reason, 1998):
- rocks,
- shallow waters,
- currents and tides,
- presence of other vessels.

The example drivers that act to propel different people down the same error-provoking pathways are as follows (Reason, 1998):
- time pressure,
- cost-cutting,
- indifference to hazards.

The local traps are characteristics of a task that, in combination with human error and violation tendencies attract people into repeated scenarios of unsafe acts or unsafe performance (Reason, 1998).

Standard occupational stress questionnaires were found not suitable for maritime industry. Instead the list of 24 stressors was customised on the basis of offshore stress scales (Langan-Fox&Cooper, 2011).

The stressors include:
- work overload,
- threat of job loss,
- demands of work day and night,
- conflicts on board and conflicts with shore based office.

Respondents rated how much stress they perceived from each of 24 items (listed in stressors questionnaire presented in figure 5) on a 5-point scale, ranking from Definitely NO to Absolutely YES (Sneddon et al., 2012).

The following questionnaires can be used for personality characteristic assessment:
- Questionnaire of Stress Sense (Plopa&Makarowski, 2010),
- Questionaire of Stimulation and Instrumental Risk (Makarowski, 2012,
- Questionaire NEO-FFI (Costa&McCrae, 2003).

The example of a questionnaire prepared for the ship masters for the assessment of the degree of stress, including the above mentioned elements - the difficult situation at sea is presented in figure 5.

No.	Difficult situation	Definitely NO	Rather NO	Difficult to say	Rather YES	Absolutely YES
1	Continuous wariness about ship's safety in aspect of fire, collision grounding					
2	Wariness about ship's safety in difficult weather condition: storm, fog, navigation in ice					
3	**Continuous wariness about possible failure of ship's equipment: main engine, diesel generators, steering**					
4	**Tiresomeness of navigation in dense traffic areas**					
5	**Frequency in and out maneuvers**					
6	**Port maneuvers in bad weather condition strong wind current**					
7	**Maneuvers in very restricted areas (small ports)**					
8	**Prolonged manoeuvring: Panama Canal, Suez Canal, Great Lakes Seaway, Antwerp, Hamburg, Buenos Aires**					
9	**Continuous wariness about safety of crew. Possibilities of accident at work, loss of life**					
10	**Conflicts among the crew members**					
11	**Low competency of crew members**					
12	**Lack of Internet access**					
13	**Various visitors on board when in port. Lack of time to rest**					
14	**Continuous, various inspections when in port**					
15	**Shortage of crew members on board**					
16	**Time stress, continuous acting in haste**					
17	**Pressure from the ship owner. (Do more and faster)**					
18	**Pressure from Charterers**					
19	**Lack of competency of shore based office people at Owners office**					
20	**Conflicts ship-shore office**					
21	**Limited relax possibilities short and busy port stay**					
22	**Work at night**					
23	**Paper work overload**					
24	**Sleeping trouble due to frequent time zones changing**					

Figure 5. Questionnaire STRESORS – Ship Master, the additional information in the questionnaire consists of age and experience as a ship master in years

4 RISK ASSESSMENT OF PORT MANOEUVRES

The further research will be based on the results of the statistical studies of ship masters and pilots' personalities and probability of their influence on stress development under particular stressors.

4.1 *Probability of error decision*

The main stressing situations - stressors – selected for manoeuvring in restricted waters and personality characteristic should be determined. The influence of age and professional experience together with the influence of stress probability on the decision error should be examined on the basis of the tests results performed on Full Mission Ship Handling simulator.

The transparent structure and possibility of risk determination in uncertainty conditions are the main reasons to implement a model based on Bayesian network (BN). BN is a technique based on probabilistic and uncertain knowledge, widely used for the risk assessment. BN is a directed acyclic graph, in which the nodes represent the random variables and arcs represent causal relationships between the nodes.

The conditional probability tables assigned to the nodes denote conditional dependencies. Based on the conditional independence of variables $A_1,\ldots, A_n$ and the chain rule, BN represents the joint probability distribution of variables $\{A_1,\ldots,A_n\}$ (Abramowicz-Gerigk&Burciu, 2014).

Probability of product of events $A_1,..,A_n$, where:

$$P(A_1 \cap A_2 \cap \ldots \cap A_{n-1}) > 0 \quad (1)$$

is determined as follows:

$$P(A_1 \cap A_2 \cap \ldots \cap A_n) = P(A_1)P(A_2 \mid A_1)\ldots P(A_n \mid A_1 \cap A_2 \cap \ldots \cap A_{n-1}) \quad (2)$$

The events $A_1, A_2, \ldots, A_n$ form the Markov chain if:

$$P(A_1 \cap A_2 \cap A_3 \ldots \cap A_n) = P(A_1)P(A_2 \mid A_1)P(A_3 \mid A_2)\cdots P(A_n \mid A_{n-1}) \quad (3)$$

The events can be replaced by binary values of random variables and then the above equations have the forms of Equations 4 and 5 (Abramowicz-Gerigk&Burciu 2014).

$$\begin{aligned} &P(X_1 = x_1, X_2 = x_2, \ldots, X_n = x_n) = \\ &P(X_1 = x_1)P(X_2 = x_2 \mid X_1 = x_1)\ldots \\ &\ldots P(X_n \mid X_1 = x_1, X_2 = x_2, \ldots, X_{n-1} = x_{n-1}), \\ &x_1, x_2, \ldots, x_n \in \{0,1\} \end{aligned} \quad (4)$$

$$
\begin{aligned}
&P(X_1 = x_1, X_2 = x_2, \ldots, X_n = x_n) = \\
&P(X_1 = x_1)P(X_2 = x_2 \mid X_1 = x_1)\ldots \\
&\ldots P(X_n \mid X_{n-1} = x_{n-1}), \\
&x_1, x_2, \ldots, x_n \in \{0,1\}
\end{aligned} \tag{5}
$$

Bayesian network for the assessment of stress influence on ship master error decision is presented in figure 6.

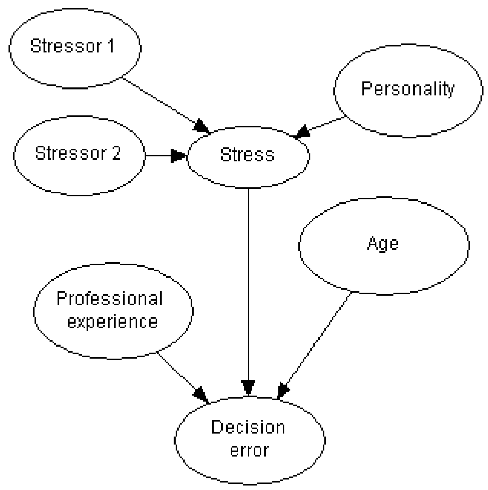

Figure 6. Bayesian network for the assessment of stress influence on ship master error decision, the states of random variable "Personality" are assumed as: open, extraverted, conscientious, neurotic, agreeable

4.2 *Risk assessment of port manoeuvres*

The example of Bayesian influence diagram for risk assessment of port manoeuvres is presented in Figure 7.

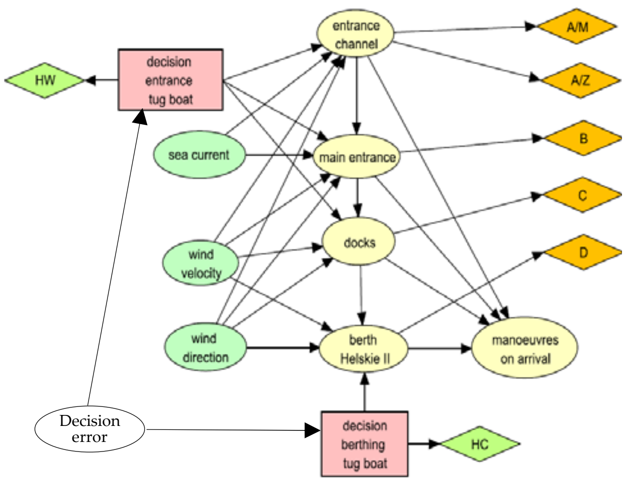

Figure 7. The influence diagram for the risk assessment of harbour accidents for the vessel entering the port. Simplified example of a ferry entering Port of Gdynia (Abramowicz-Gerigk&Burciu, 2014)

The nature nodes in the diagram represent the random variables with two states: safe and ALARP (Abramowicz-Gerigk&Burciu, 2014):

- entrance channel - probability of accident during navigation along the approach channel,
- main entrance - probability of accident during entry into the port,
- docks - probability of accident during navigation inside the docks,
- berth Helskie II - probability of accident during berthing at berth Helskie II,
- manoeuvres on arrival - probability of accident during port manoeuvres.

The nature nodes, representing external conditions are as follows (Abramowicz-Gerigk&Burciu, 2014):

- sea current - probability of occurrence of dangerous wind current, states: yes, no,
- wind velocity - probability of occurrence of dangerous wind, states: wind <7 B, wind 7 B,
- wind direction - probability of occurrence of dangerous wind, states: yes, no.

The description of utility nodes representing risk of accidents is presented in table 2.

Table 2. Description of utility nodes.

Node	Description
A/M	$\lvert A/M \rvert = R_{A/M}$ - risk of ship grounding in channel
A/Z	$\lvert A/Z \rvert = R_{A/Z}$ - risk of collision in channel
B	$\lvert B \rvert = R_B$ - risk of accident in main entrance
C	$\lvert C \rvert = R_C$ - risk of accident in docks
D	$\lvert D \rvert = R_D$ - risk of accident during berthing

The decision error node represents probability of error decision with two states: yes, no.

The example Bayesian network and influence diagram presented in the paper were developed using Hugin Researcher 7.4 commercial program for design of the network structure, data input and calculations of the joint probability distribution for the nodes.

5 CONCLUSIONS

It has been stated in several studies that incident and near miss reporting is deficient in the shipping industry and it has been recognised as the failing part of ISM code implementation (Lappalainen, 2011). For this reason there is no sufficient data for the analysis of human factor based on statistical methods. Ship motion simulation can be used to determine the risk of a particular manoeuvre (Gucma, 2009), combined with experts opinion. The weighting factors assigned to the experts give better understanding of the subjective judgement of the acceptable risk level.

Human factor modelling in the risk assessment of port manoeuvers is very important with respect to different attitudes towards the risk of marine pilots and ship masters. The psychological characteristics of ship masters and pilots, combined with identified stressors create stress. The approach proposed in the paper would allow establishing susceptibility for stress of each personality and using statistical methods defining susceptibility for stress for the population of ship masters and pilots, with respect to their age and experience as either stress moderator or accelerator respectively.

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