Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2022, 72 (144), 42–49
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/532

Received: 30.06.2022
Accepted: 21.11.2022
Published: 31.12.2022

Impact of psychological components of human factors on the probability of committing an error during ship handling in restricted waters

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Keywords: human factors, safety, psychological profile, risk, probability, restricted waters
JEL Classification: C45, C51, L91, R41

Abstract
The paper presents a new approach to the evaluation of human factor (HF) influence on the risk of maritime accidents. This approach is based on a formal human–ship–environment system definition including the relationships between humans, technology, environment, and organization. Social and organizational factors have already been included in the International Maritime Organization regulations; however, the individual factors still need investigation. A combination of psychological studies and technical operations of sea-going ships has given a huge opportunity to use HF assessment in rule-making processes. The main scientific goal of the research presented in the paper was the development of a method to assess the influence of HF on the risk of maneuvering accidents in restricted waters. This method is based on research within the area of technical ship operation and the results of the psychological profile of operators. The proposed model is based on a quantitative HF model developed by an authorized psychologist comprising personality traits, vulnerability to stress, and risk approach. The investigations were carried out with a group of 32 experienced ship masters performing a complex maneuvering task on the Full Mission Ship Handling Simulator. The multidimensional dependencies between variables of the psychological profile and the risk of an accident resulting from maneuvering errors were implemented into the Sugeno fuzzy model. The developed model allows risk assessment to be conducted that depends on the selected personality profile features. These features can be measured using psychological questionnaires, and then the risk of an accident due to maneuvering error can be calculated for a captain or marine pilot in order to improve human resource management.

Introduction

The development of ISM (negligence) and STCW (poor training) has decreased the accident rate, but only half of all human factor (HF) components have been found and defined. Therefore, we need to look further to define these components and find remedies. The article shows a different approach to the topic. Research on HF from the aspect of psychology is being carried out around the world, mainly in air transport, but not much of this research has been carried out in maritime transport (Hejmlich, 2014; Havold, 2015; Hejmlich & Abramowicz-Gerigk, 2017; Makarowski et al., 2017; Hejmlich, 2018). This paper is a description of such research performed by a doctoral student on a ship maneuvering simulator in conjunction with the use of psychological tests to determine the psychological profile of ship captains and port pilots.

In decision theory, risk relates to a situation in which the selection of a given decision entails the possibility of consequences occurring with a known probability of occurrence for each possibility (Battacharya, 2012).

Risk taking, therefore, means knowingly accepting a potential loss relaying on mathematical expectation.

$$\text{Risk} = \text{probability} \times \text{consequences}$$

Risk taking, therefore, is a compromise between safety and profit.

However, should we consider a compromise in terms of safety?

Research has shown that human error contributes to (Berg, 2013):

84–88% of tanker accidents,
79% of the grounding of tugs,
89–96% of collisions,
75% of allision,
75% of fires and explosions.

Statistics show that there are around 100,000 ships in the world and more than 2000–2500 marine accidents per year. This means the probability of each ship being involved in an accident is 0.025.

The probability of HF resulting in an accident is 0.02.

It is tempting to accept certain consequences due to a low probability, but the probability of 0.02 for heavy accidents (10% of all accidents) may mean a loss of 200 human lives per year per 2,000,000 people working at sea. This makes 10^{-4} per year, which is far away from the ALARP level of 10^{-6} for individual risk (Chauvin, 2011).

Should we control the risk by minimizing losses or by minimizing the probability of unwanted events?

HF with partly identified components are presented in Figure 1.

The Reason's model adopted for HF components is presented in Figure 2.

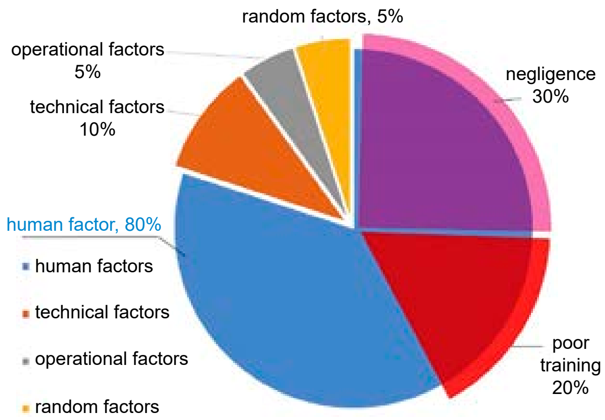

Figure 1. Human factors with partly identified components (Berg, 2013; Mokhtari & Khodadadi-Didani, 2013)

Research method

The main scientific goal of the research was to identify and assess more components of HF.

The research consisted of two parts, which were combined in the model.

- Part one: Survey of the psychological profile of each participant (Brzeziński, 1980).
- Part two: Test on Full Mission Bridge Simulator.

Survey of psychological profile

Psychological questionnaires were presented to participants:

- Sense of Stress Questionnaire (KPS) (Plopa & Makarowski, 2010).
- Stimulation and Instrumental Risk Questionnaire (RS&RI) (Makarowski, 2012).
- NEO-FFI Questionnaire (Big Five Personality Traits) (Costa & McCrae, 2003).

A qualified psychologist decoded the questionnaires and presented the results as numerical scores.

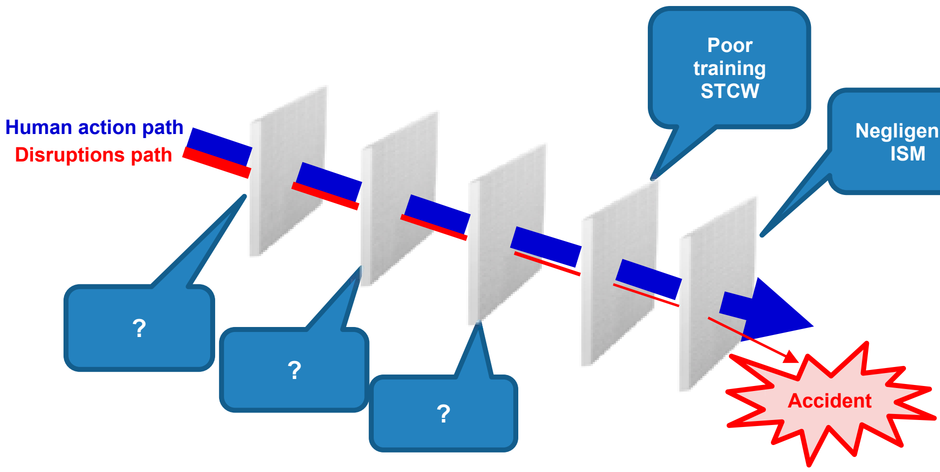

Figure 2. Reason's model adopted for human factor components

Table 1. Questionnaire scores

#	Stimulating Risk (SR)	Instrumental Risk (IR)	Emotional Tension (ET)	Internal Stress	Intrapsychic Stress (IS)
1	4	14	12	8	13
2	10	14	19	13	14
3	4	15	7	7	7
4	10	14	15	16	12
5	15	6	22	15	17
6	4	12	7	7	9
7	13	15	14	11	9
8	6	12	20	17	19
..	..	..	..	..	..
32	14	10	24	19	20

The questionnaire scores are presented in Table 1.

The most promising Pearson's correlation with committed errors numbers was found for two groups, representing risk approach attitude and stress level.

The scores for grouped components SR – IR and ET + IS are presented in Table 2.

Test on Full Mission Bridge Simulator

A simulator test was performed to run the ship all the way from a sea buoy to the berthing dock.

Errors during the passage were counted and rated. This was a time-pressure, stress-triggering situation. One area was particularly interesting: the canal bent where a strong bank effect occurs for speeds higher than 8 knots. Shortly before this bent, operators received a message about berthing scheduled in a tight time window. A screenshot from the simulator simulation showing the control point is presented in Figure 3.

Table 2. Scores for grouped components SR – IR and ET + IS

SR – IR	ET + IS
–10	25
–4	33
–11	14
–4	27
9	39
–8	16
–2	23
–6	39
..	..
4	44

As a result, 8 out of 32 experienced captains and pilots committed a fatal error and failed to stay in the canal range and finally ran the ship aground.

Results processing and discussion

Psychological survey scores were compared with the simulator performance test for each participant in both aspects: risk approach attitude and stresses level.

Figure 4 shows the influence of risk approach attitude on the simulator results.

The participants with stimulated risk scores higher than instrumental risk were rated: 5 failed and

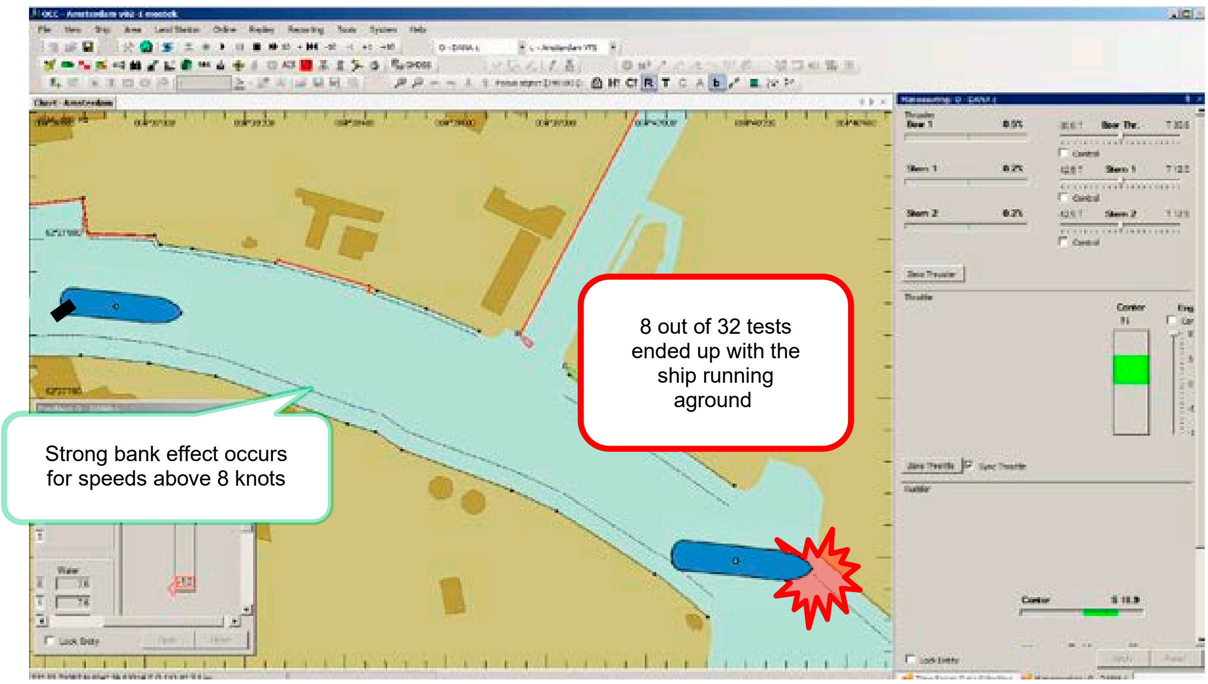

Figure 3. Screenshot from the simulator showing the control point

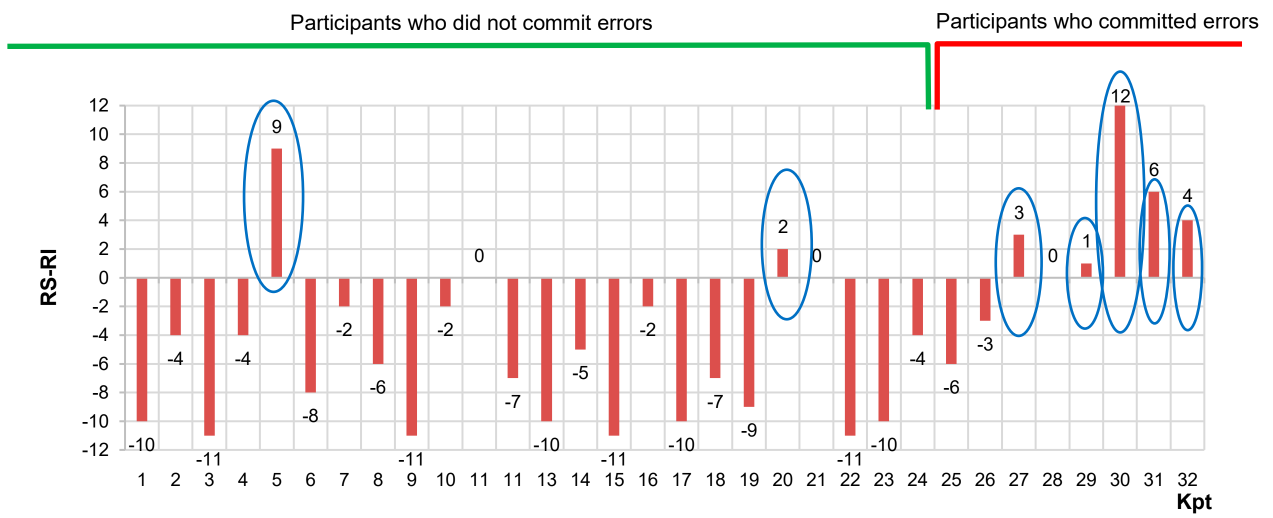

Figure 4. Diagram showing the influence of risk approach attitude on the simulator results

2 passed the simulator test. Participants with higher instrumental risk scores were rated: 1 failed and 21 passed. Participants with equal IR and SR were rated: 1 failed and 2 passed.

The total probability of having a command operator with a higher SR score (a higher probability of failure) computed with the Bayesian network was 0.11 (Figure 5).

Figure 6 shows the influence of stress level on the simulator results.

Participants with elevated stress levels above 40 were rated 4:1 fails to successes.

Respectively, the previous calculation using the Bayesian network found a total probability of a having more stressed operator was 0.18.

Additionally, both features created a higher probability of failure for 3 out of 32 participants, and all 3 failed the simulator test (Figure 7).

This experiment allowed the identification of differences in performance in aspects of various psychological profiles. It identified two components with a strong impact on safe performance during routine maneuvers. Risk approach attitude gave a probability of errors at 0.11, and stress level gave a probability of errors at 0.17. On the basis of the above results, the Reason's model (Figure 8) was supplemented with unknown "filters".

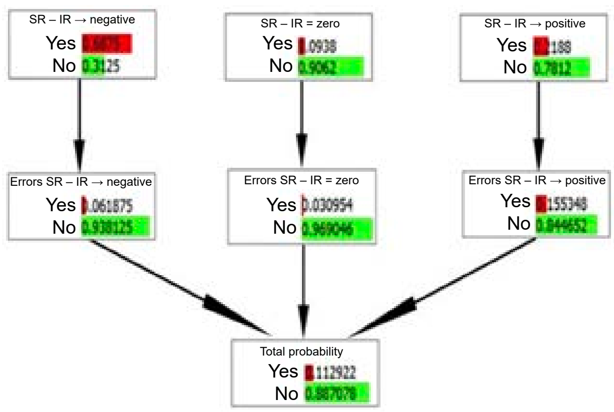

Figure 5. Bayesian network computing the total probability of higher SR scores in a population (MSBNs v.1.4.2, 2017)

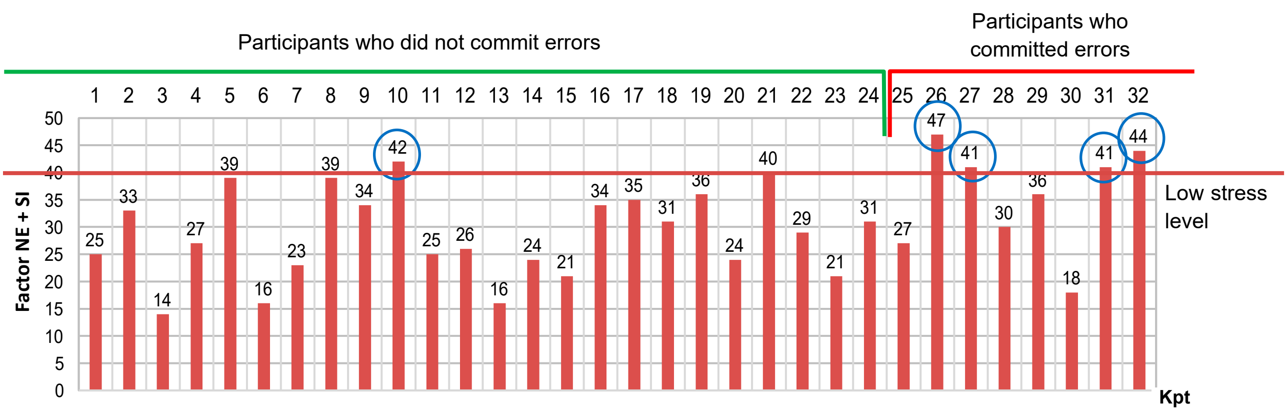

Figure 6. Diagram showing the influence of stress level on the simulator results

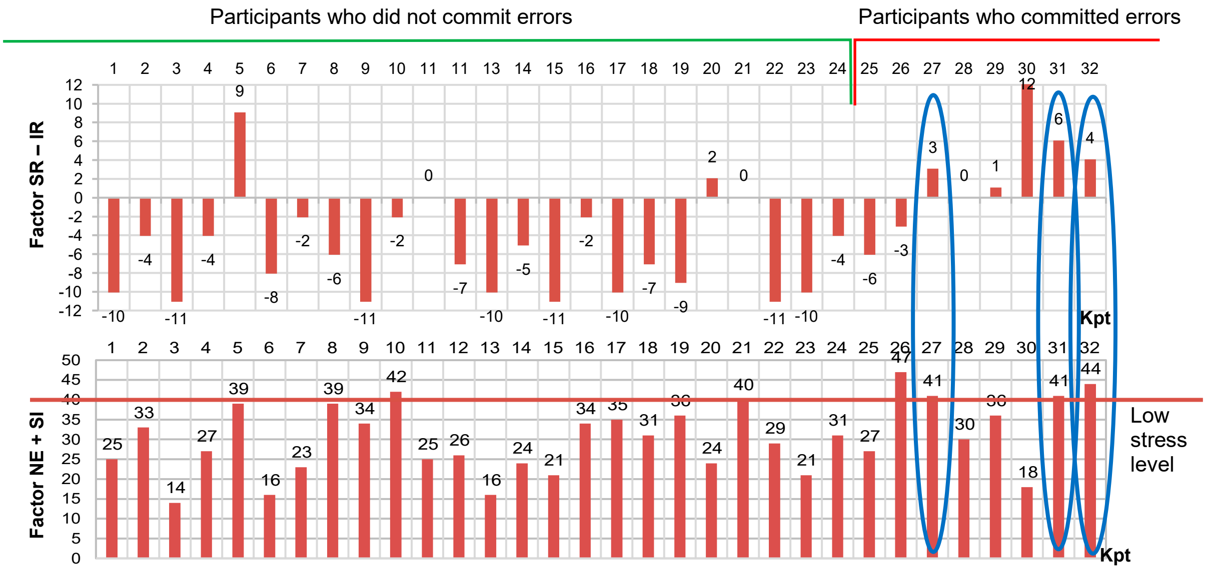

Figure 7. Diagram showing the influence of stresses level and risk approach on the simulator results

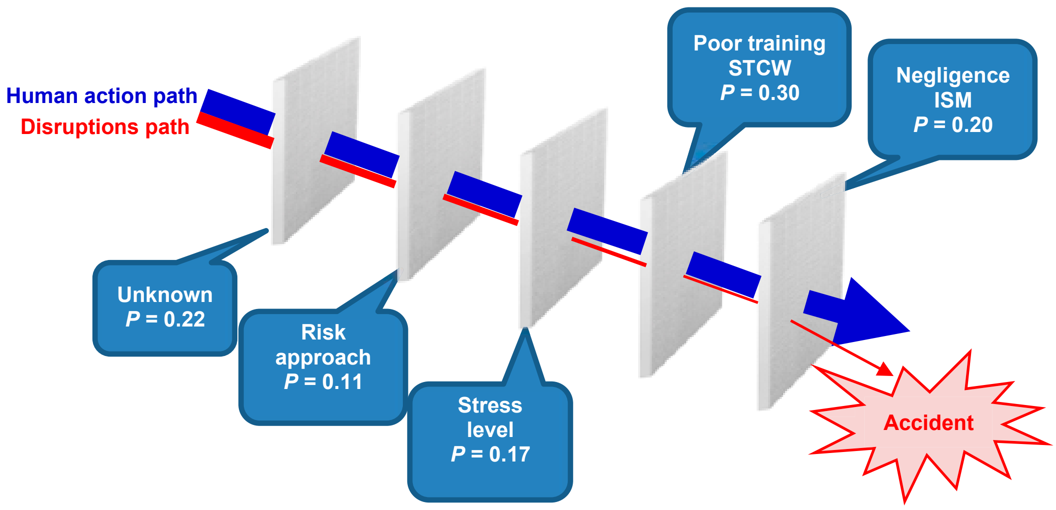

Figure 8. Reason's model supplemented with new filters

Mathematical model of the results

Five variables presented in Figure 8 were taken as input values for the Sugeno fuzzy model created in the computing environment (MatLab, 2022) (Figure 9).

The Sugeno model is a fuzzy neural network, which allows knowledge to be expressed by natural language in an easy way. It can calculate the outputs for input data out of the range initially foreseen.

The model is very stable, and small input differences generate small differences at the exit (with an appropriate structure of membership functions assignment).

The Sugeno model interface is intuitive and, thus, easy to operate.

Entering of input data is executed by moving the sliders or manual typing of data numbers in the left, lower window. Figure 10 shows the model tuned for the situation with the probability of an accident at 0.025.

Modeling of the psychological component of HF began with a reduction of risk approach attitude. In practice, this means selecting operators with an instrumental risk higher than the stimulating risk. The probability of an accident decreases to 0.020 (Figure 11).

Consequently, a decrease of stress level by a probability value of 0.01 is presented in Table 3.

The Sugeno model interface showing the results after stress level reduction by 30% is presented in Figure 12.

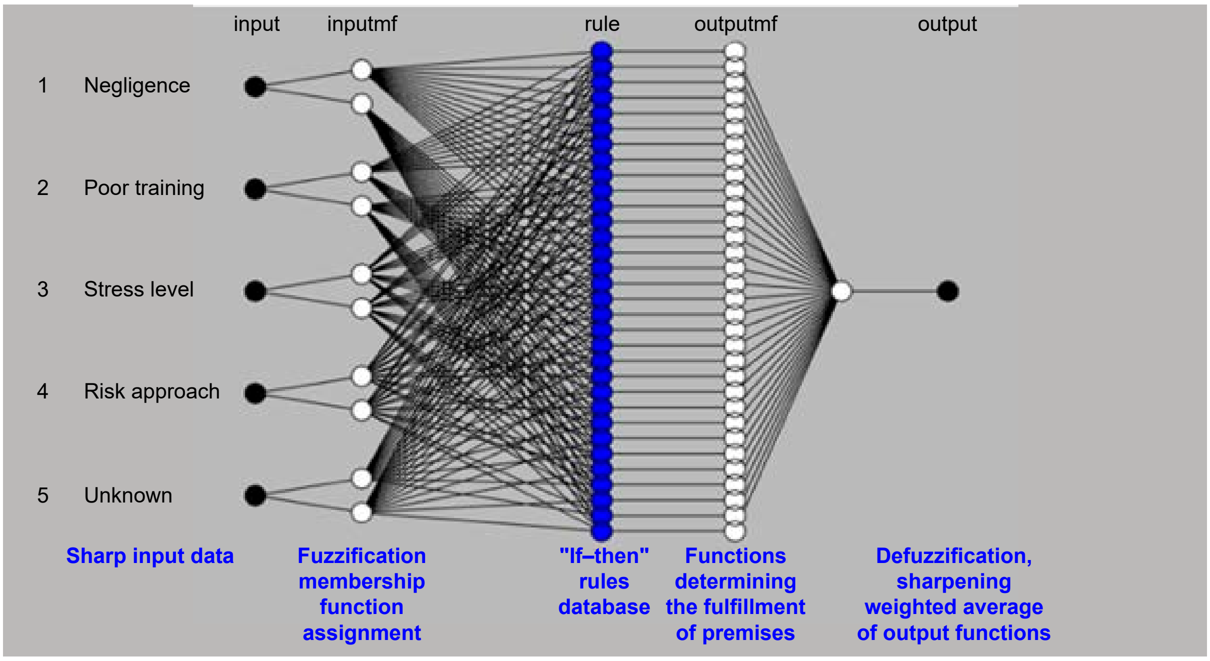

Figure 9. Sugeno fuzzy neural network model structure

Figure 10. Sugeno Model interface showing the present situation

Table 3. Results of risk approach and stress level modeling by the Sugeno model (C – column shows the present situation)

A	B	C	D	E	F	G	H	I
Risk approach max 0.17	0.17	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Stress level max 0.11	0.11	0.11	0.11	0.10	0.09	0.08	0.07	0.06
Negligence max 0.30	0.300	0.164	0.164	0.164	0.164	0.164	0.164	0.164
Poor training max 0.20	0.200	0.126	0.126	0.126	0.126	0.126	0.126	0.126
Unknown max 0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Probability max 1	1.0000	0.0240	0.0200	0.0165	0.0128	0.0090	0.0050	0.0020

Although the reduction of risk approach attitude is self-explanatory, the reduction of stress level needs further action. Table 3 shows how a reduction of stress level decreases the probability of an accident.

Risk approach reduction

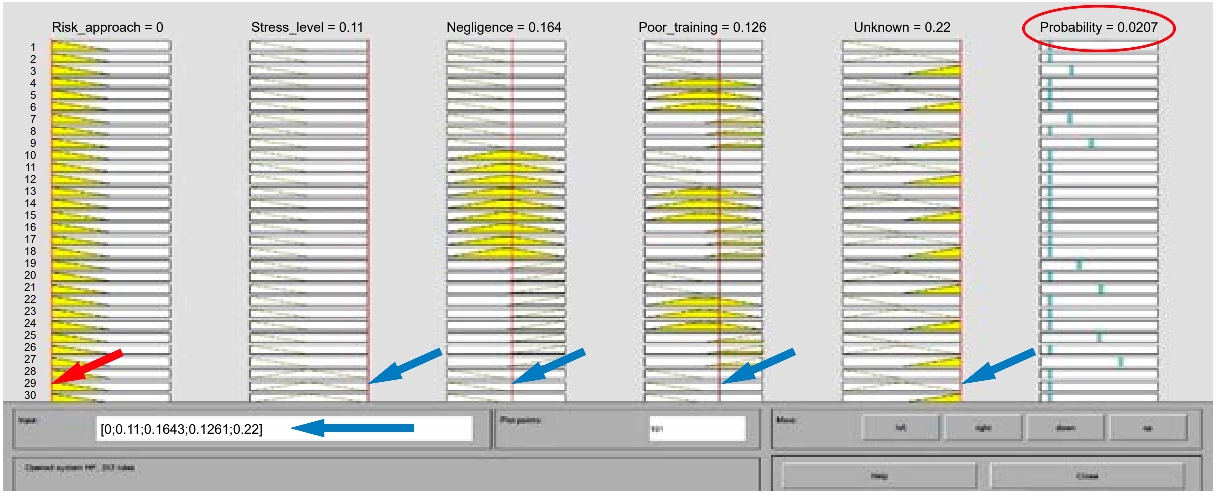

Figure 11. Sugeno model interface showing the results after stimulation risk has been eliminated (Table 3 column D)

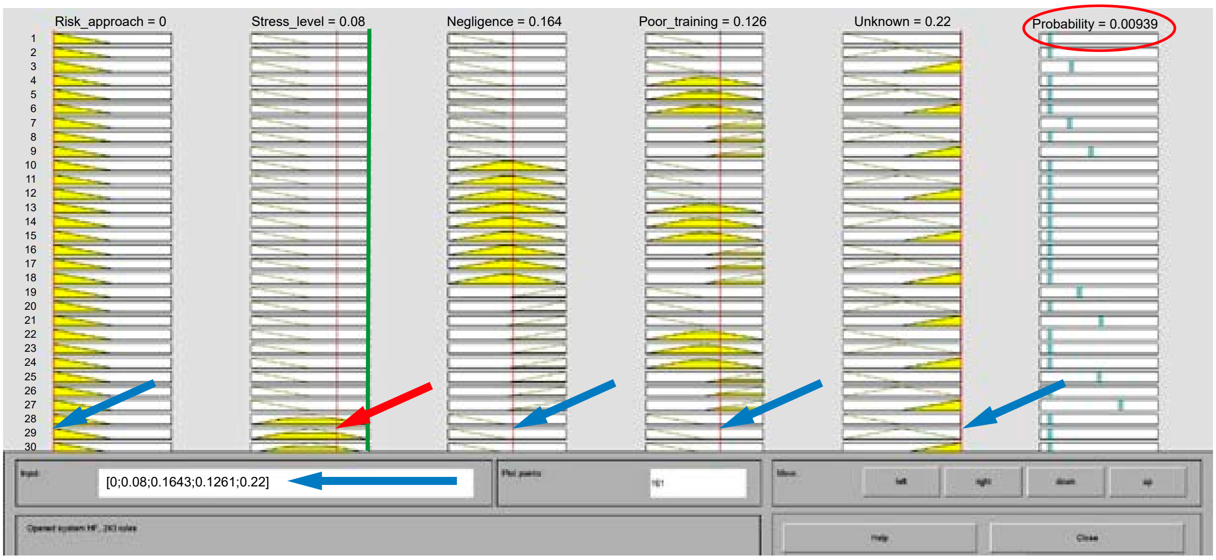

Figure 12. Sugeno model interface showing the results after stress level reduction by 30% (Table 3 column G)

Table 4. Stressors list

1. Ship safety	13. Safety of crew
2. **Crew conflicts**	14. Limited possibilities for relaxation
3. **Incompetence of the ship owner's office employees**	15. **Office-ship conflicts**
4. **Continuous port inspections**	16. Divorce
5. Wariness about jobs	17. Storm
6. Constant emergency	18. Frequency of maneuvers
7. Finances	19. Night work
8. **No Internet on ships**	20. Death of a loved one
9. **Charterer pressure**	21. **Overload with office work**
10. **No rest in port**	22. **Ship-owner's pressure**
11. Separation from family	23. Family situation
12. Safety of family	24. **Too few crew members**

During this research, participants were asked to reveal what stresses them the most at work Hejmlich, A. (Hejmlich, 2016), and a list of stressors was established (Table 4). Stressors are the factors that may trigger stress development. Stressors bolded on the list are rated as organizational factors.

Thus, stress could be easily reduced or eliminated at any level of operations on the ship, company, flag state, or IMO level.

Conclusions

The following conclusions can be drawn from the presented research:

1. Defining the components of HF allows for effective control of the probability of making an error.
2. Nine out of a hundred captains and pilots have a high probability of making an error. Thus, unpopular selection is necessary for operators in accordance with their psycho-physical abilities.
3. Reduction of stressors listed in Table 4 by legal and administrative regulations would decrease the stress triggering factors, stress level, and accident probability.
4. The proposed method would be based on a few questions – a questionnaire taken by candidates to define their psychological profile in order to assign individuals with a high probability of error-making characteristics to lower-risk tasks.
5. The method allows the "risk owner" to make a risk assessment depending on expected losses. The costs of individual and material losses are commonly known.

Acknowledgment

This research was funded by Gdynia Maritime University Grants No. WN/2022/PZ/08 and WN/2022/PZ/03.

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Cite as: Hejmlich, A. (2022) Impact of psychological components of human factors on the probability of committing an error during ship handling in restricted waters. *Scientific Journals of the Maritime University of Szczecin, Zeszyty Naukowe Akademii Morskiej w Szczecinie* 72 (144), 42–49.