TECHNICAL NOTE

HUMAN FACTORS IN SHIP DESIGN AND OPERATION: A PRELIMINARY SURVEY OF THE THEORETICAL CONSTRUCT

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SUMMARY

This technical note presents an analysis of the underlying factors of human factors in ship design based on questionnaires distributed on two offshore supply vessels operating in the Norwegian Sea. The concept of human factors in ship design is still evolving. The purpose of this paper is to present a preliminary model of the human factors construct by using a factor analysis method. The results confirm the existence of controllability, workability and habitability as the principal factors of human factors in ship design. Three other factors that emerged are cargo facilities, reliability, automation and maintainability (RAM) and interfacing complexity. Bridging variables found between these factors include elements such as safety, manoeuvring, engine room and bridge design. A preliminary model of how the components or parts relate to human factors in ship design and operation is developed. The model also indicates the parties who are responsible for the various aspects of ship design from a human factors perspective.

NOMENCLATURE

DP	Dynamic positioning
ECR	Engine control room
ER	Engine room
HF	Human factors
HSE	Health, Safety and Environment
KMO	Kaiser-Meyer-Olkin
LR	Lloyd's Register
MECE	Mutually exclusive and collectively exhaustive
OHS	Occupational health and safety
OSV	Offshore supply vessel
PAF	Principal axis factoring
RAM	Reliability, automation and maintainability
SPSS	Statistical Package for the Social Sciences

1. INTRODUCTION

A quantitative survey using questionnaires to examine the implementation of human factors (HF) in ship design was conducted [1], using the Lloyd's Register's (LR) [2, 3] eight dimensions HF framework.

The framework did not perfectly satisfy the mutually exclusive and collectively exhaustive (MECE) principle. This principle is essential for developing a good theoretical construct[1] such as human factors in ship design. The MECE principle states that a list, such as HF framework should have no overlaps and no gaps or holes. Some problems of overlap were found in the development of the coding sheet for the literature study [4, 5] and questionnaires [1], therefore, a theoretical examination of the human factors concept was undertaken.

This paper presents a preliminary verification of the human factors concept using factor analysis. This is the logical continuation of a quantitative survey of human factors which was conducted on two offshore supply vessels in summer 2011 and also reported in this publication [1]. The same questionnaires and data are used in this paper.

2. FACTOR ANALYSIS

Factor analysis has been applied in psychological research for more than 100 years, since it was developed by Spearman [6]. It is a statistical approach used to reveal relationships between a number of observable variables and looking for common unobservable (latent) factors that can explain variations measurements; in this case, in human factors implementation, which are measured by items in questionnaires. It is customary to use factor analysis for data reduction or structure detection and to identify collinearity of variables.

Factor analysis was used in this study to:

- Identify the underlying factors of human factors implementation in marine design.
- Verify the existing human factors framework.
- Reduce the number of human factors dimensions to manage.
- Provide a firm theoretical construct of human factors in marine design.

42 respondents completed the questionnaires [1]. This number of respondents is too low for a proper factor analysis, but the investigation was performed with caution and the assumptions required for the analysis were always checked. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy examines whether the partial correlations among items are small. If the variables share common factor(s) the partial correlations will be small and the KMO will be close to 1.0. The

[1] A construct can be defined as a complex idea or a conceptual theory

KMO is expected to be higher than 0.5 to be "acceptable". Bartlett's test of sphericity determines whether the correlation matrix is an identity matrix. The test should be significant (<.05).

The questionnaire consisted of 107 valid items, in four sections, to which the factor analysis was applied:

- A: Human factors direct evaluation (26 items)
- B: Personal symptoms and person-related incidents (8 items)
- C: Vessel-related incidents (8 items)
- D: Human factors Likert-scale questionnaires (65 items).

A detail description of the questionnaires is presented in the first paper [1].

2.1 HUMAN FACTORS DIRECT EVALUATION

A KMO measure of sampling adequacy and Bartlett's test of sphericity confirm that the twenty-six-items in Section A are suitable for factor analysis. The Statistical Package for the Social Sciences (SPSS) software version 14.1 [7] was used to perform factor analysis. The principal axis factoring (PAF) extraction method was utilized. The programme first explored the strongest correlation between the items and a latent factor, called Factor 1, then, continued to look for the second latent factor, Factor 2 and so forth. Finally, five factors were revealed. Rotational methods were explored to clear the results. Table 1 shows the results of the factors after being rotated using the Oblimin rotation method with Kaiser normalisation. Each row of the table shows a regression equation where the item is expressed as a function of the factors. Coefficients smaller than 0.3 were suppressed because they are negligible. Several bridging variables were identified: "overall safety", "manoeuvring", "accommodation", "engine room" "bridge design" and "alarm". Bridging variables are items which contain more than one dominant coefficient or contain several less dominant coefficients, showing overlap. Typically in factor analysis this type of variable will be omitted, however, in this research, bridging variables seem to have a different and meaningful interpretation. They are discussed in Section 3.

The results presented in Table 1 are not completely clean because some variables still contain loadings in more than one factor, namely: "DP system", "general arrangement/layout", "equipment", "overall working condition", "space" and "ECR". The first rotated factor, Factor 1 was most highly correlated with "autopilot", "navigation system" and "DP system". The second factor was most highly correlated with "system procedure", "general arrangement and layout", "storage", "equipment", "overall working condition" and "space". The third factor was closely linked with "vibration", "sound/noise", "motion", and "ECR". The fourth factor was associated with "cargo deck" and "cargo tanks". The fifth factor was highly correlated with "overall reliability", "control & maintenance" and "automation".

According to LR's HF framework, Factor 1 can be identified as "Controllability", Factor 2 as "Workability", and Factor 3 as "Habitability". Factor 4 "Cargo Facilities" and Factor 5 "Reliability, Automation and Maintainability" are not specifically contained in the framework, but are common terms found in the industry.

Table 1. Pattern Matrix of Human Factors Direct Evaluation Scale (Section A)

Item	Factor				
	1	2	3	4	5
Autopilot	0.873				
Navigation system	0.767				
DP system	0.482				0.301
System procedure		0.771			
General arrangement/ layout		0.724		0.332	
Storage		0.671			
Equipment	0.337	0.604			
Overall working condition		0.573		0.386	
Space		0.508		0.305	
Communication system and equipment		0.364			
Vibration			0.826		
Sound, noise			0.786		
Motion			0.696		
ECR	-0.306		0.664		0.358
Overall comfort			0.440		
Accommodation			0.359		
Cargo deck				0.926	
Cargo tanks				0.711	
Overall reliability					0.777
Control & maintenance					0.713
Automation					0.671
Extraction Method: Principal Axis Factoring Rotation Method: Oblimin with Kaiser Normalisation					

2.2 PERSONNEL INCIDENTS

The KMO test shows a sampling adequacy of 0.574 and Bartlett's test of sphericity shows significance of 0.000, confirming that Section B is suitable for factor analysis. Three components were extracted from the eight-item personnel incidents data in Section B using principal component analysis (PCA). The Oblimin rotation method with Kaiser normalisation was applied. Table 2 shows that the first factor has an essential correlation with the following items: "confused by the system", "misoperate a switch or control" and "fail to follow the system/procedure". The factor can be labeled as "Operational Incidents". The second factor covers: "sleep disturbance and sleep interruption", "seasickness" and "fatigue/tiredness". These are related to "Discomfort" on the vessel. The third factor is most highly correlated to following items: "stumble or hit an object by accident" and "slip, fall or loss of balance". The third factor can be labeled "Occupational Incidents". It can be seen that "fatigue and tiredness", even though it lies under "Discomfort" (Factor 2), also correlates with "Occupational Incidents" (Factor 3). This is quite reasonable, as it involves the logic that people get tired because of being uncomfortable on board ship which then leads to incidents while working.

Table 2. Pattern Matrix of Personnel Incidents (Section B)

Item	Factor		
	1	2	3
Confused by the system	0.88		
Misoperate a switch/control	0.77		
Failed to follow the system / procedure	0.73		
Sleep disturbance or sleep interrupted		0.89	
Seasickness		0.78	
Fatigue/tired		0.71	0.48
Stumble or hit an object			0.85
Slip, fall or loss of balance			0.77
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation			

Table 3. Pattern Matrix on Vessel's Incidents (Section C)

	Factor			
	1	2	3	4
Contact/collision	0.87			
Fire or explosions	0.84			
Water on deck		0.77		
Moving cargo on deck		0.72		
Loss of power/blackout			0.80	
Loss of navigation/control			0.74	
Falling objects				0.90
Bulk cargo spill				0.79
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation				

2.3 VESSEL INCIDENTS

Assumption testing is not completely fulfilled for the eight-item vessel incidence data in Table 3. The KMO measure of sampling adequacy is lower than 0.5, at 0.460, but the Bartlett's test of sphericity reaches a significant level of 0.000. Factor analysis was thus performed with extra caution. Four components are extracted from the eight-item vessel's incidence data in Section C using the PCA extraction method. The Oblimin rotation method with Kaiser normalisation was also applied. The first factor covers these items: "contact/collision" and "fire/explosions" (see Table 3). This factor can be categorised as "Major Incident". The second factor has high correlation with the following items: "water on deck", "moving cargo on deck". It can be called "Deck Incidents". The third factor consists of two items: "loss of power/black out" and "loss of navigation/control". This factor can be labeled as "Ship Operation Incidents". The fourth factor have high relationships with: "falling objects" and "bulk cargo spill". This factor can be named "Cargo Operation Incidents".

2.4 HUMAN FACTORS LIKERT-SCALE

Section D, which consists of sixty-five items, is obviously not suitable for factor analysis given "only" the forty-two responses available, however, an experimental attempt to pursue the analysis was performed. As many as eighteen factors were extracted when factor analysis was run the first time using the principal component extraction method. The eigenvalue criterion of greater than 1 was used. An eigenvalue shows how much a factor explains the variance of the items. Vague items, items with no significant loadings, and items with several cross-loadings were eliminated. After several iterations, seven components were found (see Pattern Matrix in Table 4). The Oblimin rotation method with Kaiser normalisation was applied.

The first factor consists of items related to maintenance, equipment, bridge design, layout of the vessel and systems reliability. It is quite similar to Factor 5 in the human factors direct evaluation (Section 2.1.) "Reliability, Automation and Maintainability", but here it is broader. The factor revealed here can be called "Reliability, Operability and Maintainability". The second factor consists of items reflecting difficulties and problems encountered by the crews on board, such as too many alarms, too much automation and overly complicated systems. This factor is therefore called "Interfacing Complexity". The third factor consists of items involved with manoeuvring, the DP system and autopilot. It can be called "Ship Handling and Manoeuvrability". The fourth factor consists of forms, checklists and procedures. It is then labelled "Systems and Procedures". The fifth factor is related to noise and cargo deck, and thus, it is referred to as "Deck Working Condition". The sixth factor consists of items related to the engine control room and engine room; therefore it is named "ER and ECR". The seventh factor is related to sleep and ship motion. It is identified as "Habitability".

The factors revealed from the human factors Likert-scale questionnaires can be summarised:

1. Reliability, operability and maintainability
2. Interfacing complexity
3. Ship handling and manoeuvrability
4. Systems and procedures
5. Deck working condition
6. Engine room and engine control room
7. Habitability

Table 4. Pattern Matrix on Human Factors Likert-scale (Section D).

	Factor						
	1	2	3	4	5	6	7
It is easy to do maintenance of the vessel	0,91						
It is easy to operate the equipment on board	0,76						
The system on the bridge is quite informative	0,73						
The vessel has a good layout	0,71						
Most systems have good reliability	0,69						
We have too many alarms on board		0,92	0,31				
We have too much automation on board		0,79					
The computer menu system is too complicated		0,77					
Sometimes the alarm system is confusing		0,71					
It's not easy to manoeuvre the vessel			-0,91				
The vessel has a good manoeuvring capability			-0,85				
The vessel has a good and reliable DP system			-0,79				
It is easy to manoeuvre the vessel			-0,74				
Sometimes we cannot rely on the autopilot			-0,65				
There are so many forms & checklists to fill in				0,89			
We have too many procedures to follow				0,77			
Some areas of the vessel are very noisy					-0,82		
The cargo deck is well designed					0,80		
The ECR is designed so it can be monitored and operated easily						0,81	
The ER can be maintained without any trouble						0,77	
Sometimes I can't sleep well on the vessel							-0,93
Sometimes we can feel that the vessel is moving too much							-0,84
Extraction Method: Principal Component Analysis Rotation Method: Oblimin with Kaiser Normalisation							

3. DISCUSSION

Factor analysis was performed to examine human factors construct in ship design. Some factors defined in the framework remain and some dissipate during the process. The two different human factors scales that were analysed, Section A (direct evaluation) and Section D (Likert-scale), provide similar results. Both outcomes look reasonable and valid. The grouping presented in Table 1 (from Section A) involves similar components or parts of the ship approach with each other that eventually merge into one factor. These terms are familiar to naval architects and marine engineers, and thus obviously in the scope of the work of designers and engineers. The grouping presented in Table 4 shows more complex constructs. They represent the characteristics or traits of the components presented in Table 1, and are consequently following the components being positioned or applied on board. These complex constructs were revealed as bridging components such as manoeuvrability, accommodation, general arrangement, overall working conditions and safety. They disappeared during factor analysis in Section A. These types of constructs then appeared in Section D and called “Reliability, Operability and Maintainability”, “Interfacing Complexity”, and “Deck Working Conditions”. Those terms are slightly distant from the perspective of designers and engineers but are the realities of daily life for the seafarers.

An attempt to establish a theoretical construct of the human factors was performed based on results of the factor analyses of Section A and Section D. A model was developed (Figure 1) to describe the relationships between components or parts the ship and the factors of interest. The basic components from Table 1 were positioned and connected to the corresponding HF dimensions such as autopilot, navigation system and DP system related to controllability. Parts of the ship design, related to the components, were then identified, such as hull, bridge, engine room and engine control room. The complex factors obtained in Table 2 were inserted into the model by considering their relationships with other factors. Obviously, those bridging variables came later in the model, on the right hand side of the model in Figure 1 - which also represents the consequence or the product of the proceeding factors and processes. Hull design affects a ship’s motion which in turn will influence the habitability of the vessel. Habitability is also affected by noise and vibration, which originate from the engine room. In the end, habitability will have an impact on safety and performance.

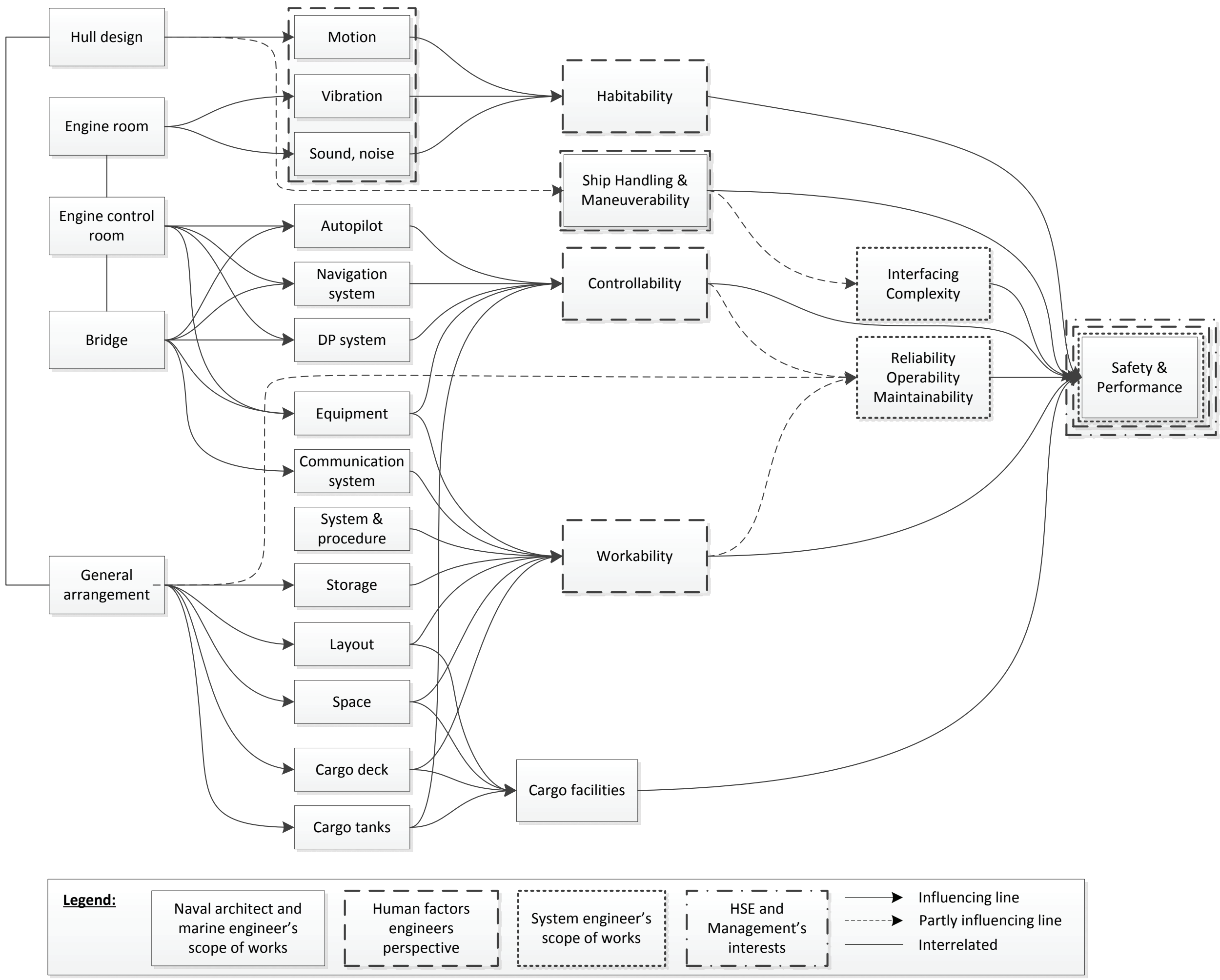

Figure 1 Inter-connectivity of human factors on ship design and operation

Hull design also makes a significant contribution to ship handling and the manoeuvrability of the vessel. It can be seen that the model is not yet complete. Ship handling and manoeuvrability are influenced by thrusters (and the rudder), which however were excluded from this process of data analysis. The items related to manoeuvrability were eliminated in the process due to weak loadings.

The model is still at its preliminary stage. The number of respondents was too small for anything except a tentative analysis. More data is obviously required. However, at this point it is safe to show that the ultimate objectives of the model are "Safety and Performance". Some of the factors may change their attributes (names) should more data and respondents be involved. Some relationships between parts and factors may also alter. It seems that some relationships still need to be explored, such as "Controllability" and "Interfacing Complexity", hypothetically should be related.

An effort was made to identify the parties responsible for the different aspects. Naval architects and marine engineers are responsible for hull design, the engine room, engine control room and general arrangement of the vessel. They are familiar with the terms of motion, vibration, noise, autopilot, navigation system, etc. The human factors engineers are acquainted with terms such as habitability, controllability and workability, while the HSE personnel is familiar with safety.

We can confidently argue that safety is inherent in all other components, parts, dimensions or constructs. Figure 1 shows a preliminary model of how these components, parts, and dimensions are connected to safety. Addressing safety as a separate entity, whether at the last stage of designing a ship or even only at the operational stage is therefore considered insufficient.

4. CONCLUSIONS

Factor analysis was used to analyse the human factors framework. The dominance of some factors is similar to the dimensions defined by the theoretical construct [2, 3]: (1) controllability, (2) workability and (3) habitability. Ship handling and manoeuvrability emerged as one factor, and three "new" factors appeared: (4) cargo facilities, (5) reliability, operability and maintainability and then (6) interfacing complexity. Several dimensions such as OHS and maintainability faded and merged into the other factors. Survivability and system safety were too weak to emerge, however, it was discovered that weak factors should not be excluded from the analysis.

They should be re-arranged and have the potential to show interconnectivity between components, parts, dimensions and constructs of human factors on ship design and operation. It is expected that this can help us address human factors issues effectively, including who should consider what issue and when.

A preliminary model of human factors considerations in ship design and operations has been presented.

Personnel incidents onboard are summarised into three factors: (1) operational incidents, (2) discomfort, and (3) occupational incidents. Vessel incidents are divided into: (1) major incidents, (2) deck incidents, (3) ship operation incidents and (4) cargo incidents. More data is required for this effort to be meaningful, and therefore, it is recommended that the study be expanded to include more respondents.

5. REFERENCES

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