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Approach to understanding navigators' ergonomic needs based on the Kano model

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Abstract

In recent years, a significant emphasis has been placed on the technological side of shipping. However, humans remain the operator of the vessel and the ones to make the final decision. With the increasing problem of fatigue, a properly designed bridge might offer great support for navigators. This includes the implementation of ergonomics in the workplace. This paper aims to better understand the needs of end-user operators and determine if there is still a need for improvement in bridge ergonomic design. To reach this goal, a custom-designed questionnaire survey of 200 professional navigators is performed. The Kano model is used to analyze the seamen's wants and needs, but also expectations based on their satisfaction with proposed ergonomic solutions. The research results suggest that there is still room for improvement in this area, which is not only a matter of comfort or health but also safety.

Introduction

Despite huge technological progress and trials of unmanned and autonomous vessels, humans remain the operator of merchant ships. Without a doubt, the advantage of bridges manned with a competent officer is the ability to validate displayed information against actual, real-life situations (Wright, 2020). Therefore, the navigator is responsible for taking the final decision about any corrective actions and, currently, is only supported by the technology. Unfortunately, many studies, like those carried out by Wang and Dai (Wang & Dai, 2012), have shown that human factors are the most common cause of maritime accidents. The International Maritime Organization (IMO) has made efforts to avoid human errors (Weng et al., 2019), including issuing the *MSC/Circ. 982: Guidelines on ergonomic criteria for bridge equipment and layout* in 2000. However, the above-mentioned document is non-mandatory, while mandatory regulation dealing with the bridge design, i.e., Regulation 15: Chapter V of the International Convention for Safety of Life at Sea (SOLAS), is only general in its scope. Thus, this paper aims to understand the ergonomic needs of professional navigators and determine if there is still a need for improvement in bridge ergonomic design.

Ergonomics is a "*scientific discipline concerned with the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance*" (International Organization for Standardization, 2011). According to

the source above, human, technological, economic, environmental, and organizational factors affect the behavior and activities of people at work. Navigators are responsible for the decisions relating to the safety of the ship, meaning that solving the ergonomic-related problems on the bridge might not only improve the well-being of seafarers, but also reduce the number of accidents caused by human error. As per the Convention on the International Regulations for Preventing Collisions at Sea (COLREG): "e*very vessel shall at all times maintain a proper lookout by sight and hearing as well as by all available means appropriate in the prevailing circumstances and conditions so as to make a full appraisal of the situation and of the risk of collision*" (International Maritime Organization, 1972). Observation requires human senses to provide inputs to the decision-making process of the navigator (Grech, Horberry & Koester, 2008). It is important to support navigators with a proper environment on the bridge, matching the individual ergonomic needs and comfort requirements, to allow efficient and unaffected work.

Studies regarding bridge ergonomics remain rare and the same can be said for seafarers' job satisfaction (Yuen et al., 2018). The industry is facing a global shortage of seamen, so shipping companies should look for solutions to attract new employees and, even more importantly, retain in-service crews (Fei & Lu, 2015). In ergonomics, compared to mechanical or structural solutions, it is difficult to directly measure the effect or estimate expected benefits and savings. To reach the goal and provide reliable results, a special questionnaire was created and distributed via professional navigators and analyzed using the Kano model, which is widely practiced in industries as an effective tool for understanding customer preferences (Xu et al., 2009). The method can be used to 'get to know' the expectations and factors that satisfy customers regarding technical products. For example, Martensen and Grønholdt (Martensen & Grønholdt, 2001) tested it and achieved excellent explanations on employee satisfaction.

Methodology

The questionnaire for this research was prepared accordingly to the assumptions developed by Noriaki Kano et al. (Kano et al., 1984); it can be divided into pairs of questions regarding the presence and lack of presence of some proposed specific features. The respondents, in this case professional navigators, are provided with single-choice questions regarding their feelings when some specific factor is implemented or not. For each question, there are five possible alternative answers, which are scaled and explained as follows:

1. I like it that way;
2. I expect it that way;
3. I am neutral with it;
4. I can live with it that way;
5. I dislike it that way.

For each respondent, each feature is classified based on a combination of answers for the pair of questions regarding its presence and lack of presence. Therefore, all attributes can be assigned to one of the following categories:

- Attractive (A) – its implementation leads to satisfaction. However, it does not cause dissatisfaction if not delivered, as it was not expected to be available. It is recommended to include a good number of attractive attributes.
- One-dimensional (O) – its inclusion helps to enhance satisfaction but cause dissatisfaction when not fulfilled. It is recommended to include a good number of one-dimensional attributes.
- Must-be (M) – the absence of this feature results in dissatisfaction, while the presence does not increase satisfaction, it is just expected to be provided.
- Indifferent (I) – causes neutral feelings, it does not enhance satisfaction or dissatisfaction, whether fulfilled or not.
- Reverse (R) – presence causes dissatisfaction, while absence results in satisfaction. It is recommended to avoid reverse attributes (Kano et al., 1984).

All the possible combinations of answers that result with respect to the assignment to categories are shown in Table 1.

There is one more category not explained before, which is known as questionable (Q). This results from conflicting responses, as opposite criteria were declared to cause the same strongly positive or strongly negative feelings. The high number of answers falling into this category might suggest that the question is incorrectly phrased, the respondents misunderstood the question, or made a mistake in marking the choice.

Berger et al. (Berger, Blauth & Boger, 1993) developed the customer satisfaction coefficient, which is considered an improvement on the Kano model. As per the source above, the coefficient helps better understand how strong implementation of each feature may impact satisfaction or how strong absence may influence user dissatisfaction. For

Table 1. Kano feature evaluation (Kano et al., 1984)

		Dysfunctional (feature is not present)				
		I like it	I expect it	I am neutral	I can live with it	I dislike it
Functional (feature is present)	I like it	Q	A	A	A	O
	I expect it	R	I	I	I	M
	I am neutral	R	I	I	I	M
	I can live with it	R	I	I	I	M
	I dislike it	R	R	R	R	Q

calculating coefficients of satisfaction (CS^+) and dissatisfaction (CS^-), the formulas defined by Berger et al. are used (Berger, Blauth & Boger, 1993); these are, respectively, written as:

$$CS^+ = \frac{A + O}{A + O + M + I} \tag{1}$$

$$CS^- = \frac{O + M}{(-1) \cdot (A + O + M + I)} \tag{2}$$

Both coefficients range from 0 to 1. However, a minus sign for the customer dissatisfaction coefficient indicates a negative influence on satisfaction, if such a feature is not fulfilled (Matzler et al., 1996). When the satisfaction coefficient (CS^+) is closer to 1, the stronger its influence on customer satisfaction. On the other hand, the closer to 0, a smaller influence is observed. Accordingly, when the dissatisfaction coefficient (CS^-) approaches –1, it means that the influence on dissatisfaction is very high if the feature is not implemented, while approaching 0 means it will not cause strong dissatisfaction when not delivered.

Questionnaire development

The research tool for this paper was a questionnaire of our own design, designated for navigators with the rank of officer of the watch or higher. It contains 6 demographic questions describing respondents and 22 questions forming pairs to assess 11 features accordingly to the Kano model requirements. The 11 potential requirements of the navigators were:

1) Energetic music on the bridge;
2) Automatic volume optimization for GMDSS;
3) Adjustable chair on the bridge;
4) Shock mitigation seat on the bridge;
5) Chair assigned to each navigator (no need to adjust on every watch);
6) Automatic adjustment of brightness and lighting on the bridge;
7) Manual and local adjustment of temperature;
8) Training in ergonomics for navigators;
9) Equally illuminated bridge during watch;
10) Reminders about proper ergonomics during watch;
11) Simplicity (short familiarization) of new equipment or solutions.
12) Inclusion of full questionnaires in English, which were distributed to navigators (see Appendix A for details).

Sample and data collection process

The data collection for this research was carried out in the form of an online questionnaire, which could be filled in using English or Polish. The questions in both languages were the same, so the answers were consolidated at the end of the data collection process. In total, 200 filled-out surveys were obtained. The questionnaire was distributed, alongside another one on the same topic of bridge ergonomics, for the purpose of further studies. Both were designed in a manner that prevents the possibility of missing answers or filling out the questionnaire incorrectly. All of them were also checked manually; it was assumed that all were filled in correctly.

The distribution started on 16 December 2021 and finished on 25 August 2022. Each navigator was asked to fill out the questionnaire only one time. As the selected respondents are a very specific group, to minimize the risk of answers originating from unqualified persons, the questionnaires were distributed via shipowners or crewing agencies. In this way, a desirable level of confidence was obtained. However, the data collection period was prolonged due to the necessity of filling out the forms by respondents who are usually onboard a ship.

Additionally, along with two custom-designed questionnaires, there were 6 demographic questions used as a verification method for the respondents that act as a tool for further analyses. Each navigator was asked for their rank, age, country of studies, highest obtained license, consolidated sea time (for ranks of the officer of the watch, chief officer,

and master), and type of present or last ship. Participants were studying for the job of navigator in 13 different countries. The questionnaire was filled in by 103 officers of the watch (51.5%), 38 chief officers (19%), 52 masters (26%), and 7 navigators working in other ranks, but holding at least officer of the watch license (3.5%). The distribution of the ranks of respondents is shown in Figure 1.

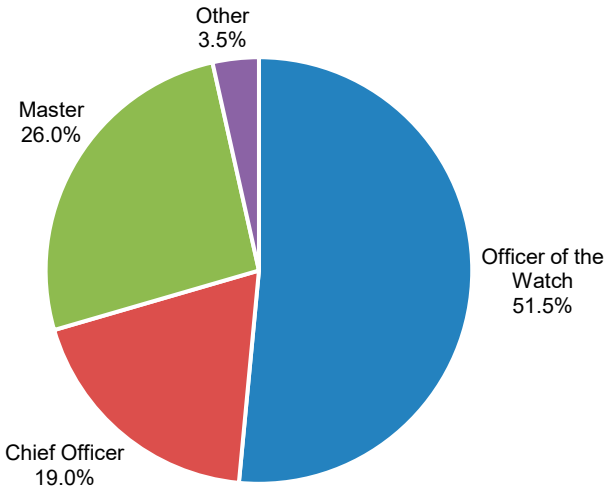

Figure 1. Ranks of navigators participating in the questionnaire research

Results

In the Kano model, the attribute category is assigned based on the combination of answers for each respondent separately. All responses are then summed up and the final category of each feature is the one that occurred in the group most frequently. The full results of the questionnaire research are presented as the percentage distribution of the obtained categories, as shown in Table 2.

Tabulated results show that the proposed attributes only fall into attractive, indifferent, and one-dimensional categories. No feature was assigned to the reverse category; therefore, no proposed solution would cause strong dissatisfaction if implemented on the bridge. The observed percentage of questionable results was not higher than 2% in any case.

Berger et al. (Berger, Blauth & Boger, 1993) proposed a graphical Kano diagram, where each attribute is represented as a pair of satisfaction and dissatisfaction coefficients. Those values are calculated using equations (1) and (2), which are explained earlier in this paper. Customer satisfaction coefficients for each feature, obtained in this research, are presented in Table 3.

To present the categories in a more precise way, not just described by one word, a Kano diagram is created and illustrated in Figure 2. Each point has coordinates represented by the obtained satisfaction coefficients from Table 3. The nature of the navigators' requirements regarding ergonomic needs can be delineated by the quadrant into which the point falls.

The diagram reconfirms that the results fall into 3 categories. Adjustable chairs on the bridge, shock mitigation seats, automatic adjustment of brightness and lighting of the wheelhouse, and short familiarization with new equipment are considered by navigators as attractive. The possibility of playing energetic music during the watch, automatic volume optimization for GMDSS, a chair assigned to each navigator, ergonomics training, an equally illuminated bridge, and reminders about proper ergonomics during the watch are in the indifferent category. Only one attribute proposed in the questionnaire is described as one-dimensional: manual, local temperature adjustment on the bridge subject

Table 2. Category of proposed features according to the Kano model

Attribute	Must-be (M)	Excitement (A)	Indifferent (I)	One-dimensional (O)	Reverse (R)	Questionable (Q)	Category
1. Energetic music	3.5%	16.0%	40.5%	7.0%	32.0%	1.0%	(I)
2. GMDSS automatic volume optimization	5.5%	29.0%	42.0%	15.0%	6.5%	2.0%	(I)
3. Adjustable chair	6.0%	38.0%	23.5%	29.0%	2.5%	1.0%	(A)
4. Shock mitigation seat	1.5%	44.5%	32.0%	18.5%	3.0%	0.5%	(A)
5. Chair assigned to each person	1.5%	36.0%	51.0%	6.0%	4.5%	1.0%	(I)
6. Automatic adjustment of brightness and lighting	1.0%	42.5%	42.0%	9.5%	4.0%	1.0%	(A)
7. Manual adjustment of temperature	12.0%	26.5%	22.0%	38.5%	0.0%	1.0%	(O)
8. Training in ergonomics	2.0%	24.5%	61.5%	5.0%	5.5%	1.5%	(I)
9. Equally illuminated bridge	7.0%	22.0%	49.5%	12.0%	8.0%	1.5%	(I)
10. Reminders about proper ergonomics	1.0%	14.0%	56.5%	3.0%	24.5%	1.0%	(I)
11. Short familiarization with new equipment	5.0%	41.5%	33.5%	14.5%	4.0%	1.5%	(A)

Table 3. Customer satisfaction coefficients (CS^+ and CS^-)

Attribute	CS+	CS–
1. Energetic music	0.343283582	–0.156716418
2. GMDSS automatic volume optimization	0.480874317	–0.224043716
3. Adjustable chair	0.694300518	–0.362694301
4. Shock mitigation seat	0.652849741	–0.207253886
5. Chair assigned to each person	0.444444444	–0.079365079
6. Automatic adjustment of brightness and lighting	0.547368421	–0.110526316
7. Manual adjustment of temperature	0.656565657	–0.51010101
8. Training in ergonomics	0.317204301	–0.075268817
9. Equally illuminated bridge	0.375690608	–0.209944751
10. Reminders about proper ergonomics	0.228187919	–0.053691275
11. Short familiarization with new equipment	0.592592593	–0.206349206

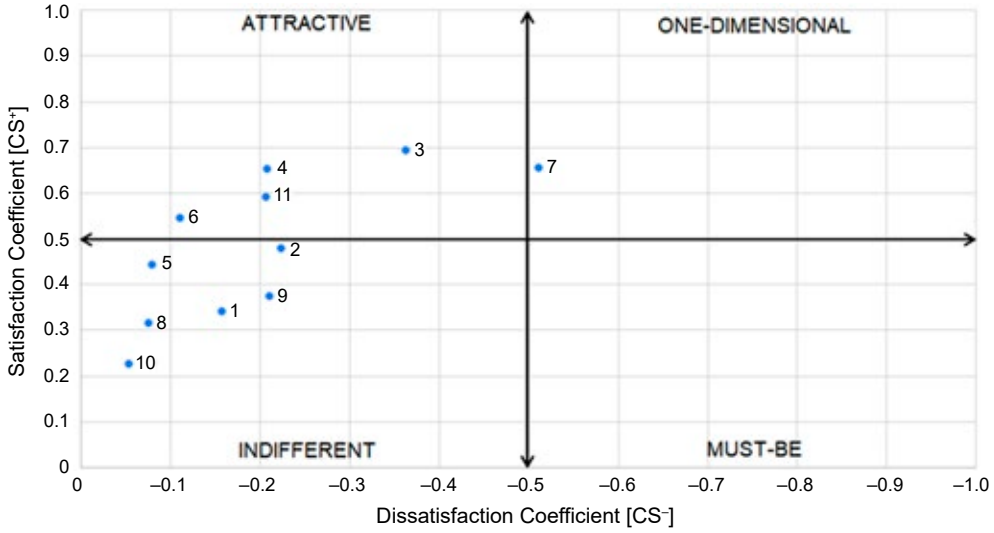

Figure 2. Kano analysis diagram

to individual needs. To sum up, there are 4 features described as attractive, 6 as indifferent, and 1 as one-dimensional.

Discussion

The Kano diagram can provide an improved understanding of the impact on the satisfaction of each proposed feature. Moreover, it can be used to prioritize solutions and verify the real implementation needs. The graph of Figure 2 indicates that some attributes approach another category that they are not finally assigned to. For example, automatic volume optimization for GMDSS (number 2) is classified as indifferent; however, it is very close to the attractive quadrant. In this case, rejecting to implement such a solution on the bridge might not be entirely reasonable. Considering the margin of error of the research, it is possible that this attribute could potentially be an attractive one if the sample size were different. A similar situation can be observed regarding the only one-dimensional feature, i.e., manual temperature adjustment on the bridge subject to the navigator's needs (number 7). The point is approaching the attractive quadrant; however, without doubt, its dissatisfaction coefficient (CS^-) is the highest, so if not implemented it will have the strongest impact on the dissatisfaction of the operator relative to all the other proposed attributes. On the other hand, the adjustable chair on the bridge (number 3) is the most expected by the navigators since it has the highest coefficient of satisfaction (CS^+).

Most features were assigned to the indifferent category, which means that they will not affect the navigator's satisfaction or dissatisfaction if provided on the bridge. No attribute falls into the must-be category, implying that no proposed feature can make navigators strongly dissatisfied if not present on their bridges. The attribute that received the most assignments to reverse category was the possibility

of using energetic music during the duties on the bridge. For 32% of respondents, implementing such a feature on the bridge would more likely cause dissatisfaction rather than satisfaction. However, playing music during the watch is unnecessary if it is not preferred. Interestingly, the average age of those who assigned this attribute to the reverse category was 45.9 years, while those who considered playing music on the bridge as attractive, one-dimensional, or even must-be were 35.0 years old on average. This difference cannot be ignored since the average age of all navigators filling out the questionnaire was 40.1 years.

In determining the potential for improvements in the area of bridge ergonomics, the attributes of attractive and one-dimensional categories should be taken as a guide. As per the Kano model, those are the features that will satisfy the navigators if implemented and are performing well. Requirements described as attractive are to be treated as something above the present expectations, which will excite operators if included. The need for clear regulations in the area of ergonomics can be explained with the example of an adjustable chair on the bridge. The IMO recommended providing such a chair in MSC.982, i.e., a non-mandatory document issued in 2000. After many years, it still arises that having an adjustable chair on the bridge is considered attractive, having some added value but not something obvious and expected in the workplace.

In all cases, the observed low percentage of answers assigned to the questionable category suggests the good quality of the research. It is worth highlighting that needs are constantly changing, as well as their categories; namely, what excites today may be a basic need in the future (Kano, 2001; Raharjo et al., 2010). For example, the study by Witell and Fundin (Witell & Fundin, 2005) found that, when the e-service was introduced, it was perceived as indifferent but was considered attractive after a short time. Put simply, the customers started to understand the importance of that particular attribute. This example shows that rejecting features classified as indifferent is not always necessary; however, it is reasonable to prioritize other solutions first.

Conclusions

Practical knowledge remains highly valuable and should be considered during the process of bridge or equipment design. This paper has analyzed navigators' ergonomic needs by evaluating 11 proposed attributes using the Kano model and a custom-designed questionnaire. Responses were obtained from people who had studied their profession in 13 different countries.

The results were presented in the form of tables and graphs, which confirmed that 4 of the proposed features fall into the category of attractive, 6 into indifferent, and 1 into one-dimensional. The categories will probably change with time because of the continuous changes in needs and standards, not only in the maritime industry but in all technical sectors. Most likely, attributes that excite today will in future not be considered as something above expectations, i.e., they will become just necessary to be included.

Noticing no attributes assigned to the must-be category, it can be concluded that the proposed ergonomic solutions are not an absolute need for the operators. However, implementing the features of the attractive and one-dimensional categories will increase the satisfaction of the navigators. Companies that provide such added-value solutions on the navigation bridges, which shipowners might use to solve modern problems, will likely become more attractive to new or current workers. The financial benefits from ergonomic investments might not be easily visible; however, they result in a long-term improvement in safety and a reduced number of accidents caused by improper lookouts, fatigue, or lack of focus. The impact of ergonomics on the safety of the ship and the performance of the navigator requires further studies. This research, however, proves that there is still room for improvement in the area of bridge ergonomics.

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APPENDIX A: WORKING CONDITIONS ON THE BRIDGE

This research questionnaire is designated for all navigators holding at least OOW/3rd Officer license.

Please DO NOT consider this research questionnaire as an attempt to verify your competencies. This questionnaire is anonymous, there are no good or bad answers; every answer is good and important. For this research, ***you are considered an expert****. Do not worry if you are unsure about something; this is NOT a test.*

Kindly fill out this questionnaire with true and honest answers because this research and results may improve your working environment and the quality of lives of navigators in future. Thank you for the few minutes of your time.

To start with, we need something about the expert, so this is about you:
Rank (present or last ship):
Age:
In which country did you study (learn to work as a navigator):
Highest license obtained:
Consolidated sea-time in ranks of OOW+CHIEF OFF+MASTER (in years):
Type of ship (present or last ship):

Questionnaire

In this part, you will express your feelings about HAVING and NOT HAVING something or some device characteristics. Just rate how much you like the given factor when you HAVE it and how much you like it when you DO NOT have it. In both cases, there is a 5-point scale like this (each with an explanation):

1. *I like it that way – you are very happy about this*
2. *I expect it that way – you believe it should be like this*
3. *I am neutral with it – no positive or negative feelings about this*
4. *I can live with it that way – you can tolerate if it is like this*
5. *I dislike it that way – you do not want it to be like this.*

LET'S START:

1.	*How would you feel if you COULD make use of energetic music during your duties?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you COULD NOT make use of energetic music during your duties?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
2.	*How would you feel if you HAD automatic volume level optimization of GMDSS radio in areas of "noisy" communication?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE automatic noise level optimization of GMDSS radio in areas of "noisy" communication (you would adjust the volume manually by yourself)?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
3.	*How would you feel if you HAD on the bridge an adjustable chair with adjustable height, backrest, headrest, and armrest?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE on the bridge an adjustable chair with adjustable height, backrest, headrest, and armrest?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
4.	*How would you feel if you HAD on the bridge shock mitigation seat (that absorbs vibrations) during storm/heavy rolling/vibrations?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE on the bridge shock mitigation seat (that absorbs vibrations) during storm/heavy rolling/vibrations?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*

5.	*How would you feel if you HAD on the bridge ergonomic chair only for you (not necessary to adjust it to your needs before each watch)?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE on the bridge ergonomic chair only for you (imagine you had such a chair, but you would have to adjust it after somebody before each watch)?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
6.	*How would you feel if you HAD something that would adjust the brightness of devices and lighting of the room for you during your watch?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE anything that would adjust the brightness of devices and lighting of the room for you during your watch (you had to do it manually by yourself)?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
7.	*How would you feel if you HAD the possibility of adjusting the temperature on the bridge subject to your needs?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE the possibility of adjusting the temperature on the bridge subject to your needs?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
8.	*How would you feel if you HAD training in the field of work ergonomics on the bridge?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE any training in the field of work ergonomics on the bridge?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
9.	*How would you feel if you HAD equally illuminated bridge (wheelhouse) during navigation duties?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE equally illuminated bridge (wheelhouse) during navigation duties?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
10.	*How would you feel if you HAD during your watch reminders for maintaining proper ergonomics on the bridge?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*How would you feel if you DID NOT HAVE during your watch reminders for maintaining proper ergonomics on the bridge?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*
11.	*If familiarization with a new system or device would require LESS than 15 minutes?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*	*If familiarization with a new system or device would require MORE than 15 minutes?* *1) I like it* *2) I expect it* *3) I am neutral with it* *4) I can live with it* *5) I dislike it*