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An Ergonomic Approach for Optimized Layout of Training Ship's Bridge

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Abstract : *To propose an ergonomic layout on the bridge, this study conducted a usability evaluation on the on-bridge navigational equipment of a college training ship that is in use at present. Through the usability evaluation on the training ship navigators, the possibility of operational errors with navigational equipment, the possibility of readout errors with display devices and even the effect of navigational equipment on navigation were evaluated beyond the scope of existing layouts, which adopt only the importance and usage frequency of navigational equipment. By taking ergonomic variables into consideration, this study suggested an optimized layout for on-bridge navigational equipment using a mathematical programming model.*

Key words : *ship's bridge, layout, ergonomics, usability evaluation, maritime accident*

1. Introduction

Ships are one of the major forms of transportation for international exchange, and due to increases in global trade and developments in scientific technology, ships are becoming increasingly larger, faster and more fully-automated. However, marine accidents still occur regularly.

The fact that 60%~80% of actual marine accidents are caused by human error indicates the potential risks related to a ship's operation (Hwang and Lee, 1999; Kim et al., 2001; Yang, 2004) as well as potential damage to the marine environment. As the rate of marine accidents due to human error is so high, a good deal of research has been conducted on this topic, yet accurate classification and survey methods have not yet been adequate enough to get a clear insight into what is taking place. Diverse efforts need to be invested to reduce the rate of marine accidents from human error. Ergonomic factors are increasingly being considered for sailing equipment along with institutional supplementation and support system maintenance.

The bridge of the ship is where a ship's officers actually work and functions as an information situation room and a navigation control room(Kemp P. 1994).

Therefore, in the case of ship design, an ergonomic bridge design should be considered to allow the officer to conduct their operations properly, be adaptable to each given situation by monitoring the sailing environment and physical function of the ship, as well as to minimize the effects of fatigue on officers due to the overburden of work (Lee et al., 2008; Ha et al., 2002).

To propose an ergonomic layout on the bridge, therefore, this study conducted a usability evaluation on the on-bridge navigational equipment of a college training ship currently in use. In general, there are many layout-only programs that have been developed to solve problems related to layouts. In fact, many new layout standards have been applied to the layout of control panels, such as spatial compatibility, usage frequency, importance and usage order principles.

Composing the main console of control panels installed on a ship's bridge, navigational equipment varies in form depending on each manufacturer, and ship owners' choices of equipment are so variable that all kinds of products made by different specialized manufacturers are mixed together during the purchasing process and are consequently used together. Therefore, although some ships may have the same design form, they do not necessarily have their navigational consoles in the same layout.

Therefore, when a ship's bridge is built, unlike automobiles or airplanes, it should be designed after being prudently studied from a navigator's viewpoint since

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navigators are to be the end users (Lee, 1997).

The existing research was mostly conducted on the panel layout, considering only the importance and usage frequency of on-bridge navigational equipment, but this study attempted to provide an optimized plan for on-bridge navigational equipment using a mathematical programming model (Cem Canel, 1996), based on ergonomic variables, such as the possibility of operational errors and readout errors and the effect of each item of navigational equipment on actual navigation.

Besides that, this study suggested an optimized layout by considering the weighted value of each item of on-bridge equipment, on the basis of the manual for coping with emergency situations that can take place while a ship is being navigated (ICS, 2007).

2. Method

2.1 Usability Evaluation

Although the required equipment varies according to the ship's type or size, generally between 40 to 80 control or display devices are necessary for ship navigation. The subject was the university training ship, and the survey asked its operators about the importance of, usage frequency of, influence on voyage of, possibility of error from, and error experience gained related to the operation of a total of 75 pieces of equipment from the model ship, including navigational equipment and control and display devices. After evaluating their usability and optimization, this study suggests an optimal ergonomic layout of on-Bridge navigational equipment.

Fig. 1 Bridge of training ship

Fig. 1 shows the inner view of the bridge of the navigation training ship used to optimize the layout of navigational equipment. The size of navigational equipment and the distance between each item were actually measured (Fig. 4).

Table 1 shows the characteristics of each piece of equipment within the bridge of the training ship when selected as a model for an actual ship's layout evaluation. It lists the evaluation scores of the training ship navigators on the actual dimensions (width×height) of 75 pieces of navigational equipment and control/display devices, and their panel dimensions, importance factor of optimization performance, usage frequency of each item of equipment, influence of the equipment on a voyage, and the possibility of error are listed.

The research also accounted for different types of emergency (collision, grounding, fire & explosion, sinking, and machinery damage) and each of these criteria was accordingly weighted in the final analysis.

Table 2 describes the nature of marine accidents that occurred in Korea during the period 2003~2007(Oh, 1992). It includes a list of the percentages(%) calculated of the sum of each type, and the results were given as weights for each piece of sailing equipment and control or display devices.

For example, when values used to perform the optimization for this study were examined with No. 4-1 "No.2 Auto tel & Inmarsat-f tel" , the score calculated using the usability evaluation of navigational equipment was a total of 20, in combination of such items as importance (5.33), usage frequency (5.67), effect on actual navigation (3.33) and operational or readout errors (5.67), as shown in Table 1. As shown in Table 2, the weighted values were calculated by using the composition ratio (27.3%) in the collision item out of all the marine accidents.

Table 3 indicates that 4-1 "No.2 Auto tel & Inmarsat-f tel" is a navigational device used for marine accidents such as fire, explosion, stranding and sinking, and the numbers in brackets mean the number of times this equipment has been used. When the weighted values of this equipment were calculated for "sinking" accidents, it was found that this equipment accounted for the third, fourth, and eleventh sinking accident-coping situations in the checklist of the Emergency Situation Manual (ICS, 2007), showing the accumulated number of times it has been used. That is, it was found that this equipment had been used a total of 3 times. Therefore, the values obtained by multiplying the composition ratio of accidents and the accumulated number of times the related equipment has been used for an emergency situation as well as the usability evaluation value for this equipment were used to perform the final optimization.

Table 1 Characteristics of each item of equipment in Bridge

No.		Equipment	Area (width×height) Total	Area (width×height) Panel	Importance	Frequency	Influence	Possibility
1		Auto pilot & gyro compass	480×600	-	6.33	6.67	6.67	5.67
2		Chart	1050×750	-	5.67	5.00	5.00	4.67
3		Route planning system	310×470	310×320	-	-	-	-
4	1	No.2 Auto tel & Inmarsat-f tel	520×800	350×270	5.33	5.67	3.33	5.67
	2	Watertight sliding door		300×210	5.33	2.67	3.00	5.33
	3	Wind Speed-direction indicator		170×170	6.00	6.33	6.00	6.00
	4	Sel. Sw. for DGPS		170×70	5.33	4.33	4.33	5.33
	5	Dimmer sw for telephone directory		60×80	2.67	3.67	2.00	6.00
	6	Remote reset unit		100×100	3.50	3.00	3.00	5.00
5	1	Doppler Speed Log display unit	370×650	130×210	-	-	-	-
	2	No.1 DGPSS lave display unit		370×260	-	-	-	-
	3	Remote unit for wind speed-direction ind		70×100	-	-	-	-
6	1	Heated Glass Control panel	250×660	250×250	3.33	2.33	3.33	6.00
	2	Cvs control panel		120×120	3.67	2.33	3.00	6.33
	3	Search light remote control panel		220×130	3.67	3.67	3.33	6.00
7	1	Outside light control panel	600×460	210×460	4.67	5.00	3.33	6.00
	2	Sensor control panel		210×180	3.33	2.67	2.67	6.00
	3	Navigation light control panel		180×230	6.67	6.67	6.67	6.00
	4	Activate		80×80	-	-	-	-
	5	Signal light control panel		180×230	5.67	3.67	5.00	5.67
8		X-band radar	610×520	470×350	7.00	7.00	7.00	4.33
··· Ellipsis								

Table 2 Types of maritime accidents182

Type / Year	Collision	Contact	Grounding	Fire & Explosion	Sinking	Machinery damage	Distress	Death or injury	Others	Total
2003	182	9	65	53	50	57	21	-	94	531
2004	210	12	75	57	69	147	45	1	188	804
2005	172	10	46	71	45	166	16	2	130	658
2006	167	17	66	41	25	195	11	1	134	657
2007	148	9	39	37	19	185	8	1	120	566
Total	879	57	291	259	208	750	101	5	666	3,216
Percentage (%)	27.3	1.8	9.0	8.1	6.5	23.3	3.1	0.2	20.7	100

The weighted values for other kinds of emergency situations were calculated in the same way, and during this process, the optimization of on-bridge navigational equipments was carried out.

The table above represents the investigation results on the navigational equipment required by the manual for each emergency, departure and arrival.

The numbers here correspond to the order of the counter-respond manual examples of Table 4. For example, the Chart(no.2) of Table 3 includes the numbering of each emergency situation and departure/arrival. "10" is assigned for the ship's "Sinking", and this number indicates that during an emergency situation in Table 4, which is the ship's sinking, this equipment will be used for the 10th order, "when needed, implementation of arbitrary sinking". In other words, the numbering of Table 3 for each item of equipment and each situation means that the equipment in the corresponding order will be used for each situation.

The number of this system shows the cumulative usage frequency of each kind of equipment for the corresponding

Table 3 The usage frequency of each item of equipment in an emergency

No.		Equipment	Condition						
			Departure	Arrival	Fire/ Explosion	Collision	Grounding	Sinking	Machinery damage
1		Auto pilot & gyro compass	3,5	3,9			24		
2		Chart	1,2,5	1				10	2
3		Route planning system	1,2,5	1					
4	1	No.2 Auto tel & Inmarsat-f tel		13,17	1,12,13,20	9,16	3	**3,4,11(3)**	4,12
	2	Watertight sliding door	9		5		8		
	3	Wind Speed-direction indicator			4				
	4	Sel. Sw. for DGPS							
	5	Dimmer sw for telephone directory							
	6	Remote reset unit							
5	1	Doppler Speed Log display unit	5			27	24		9
	2	No.1 DGPSS lave display unit	5			25	15,31		8
	3	Remote unit for wind speed-direction ind	5						
6	1	Heated Glass Control panel							
	2	Cvs control panel							
	3	Search light remote control panel							
7	1	Outside light control panel				8			
	2	Sensor control panel							
	3	Navigation light control panel	10		16	12			5
	4	Activate							
	5	Signal light control panel	10		16	12	4		5
8		X-band radar	5		4	22,25	24		1
··· Ellipsis									

Table 4 Emergency circumstance - Grounding

Sequence	Countermeasure	Check	Number
1	Operate emergency bell in the ship	Gen & Em'cy alarm, Public Address system	9-5, 9-6
2	Deploy emergency department	Gen & Em'cy alarm, Public Address system	9-5, 9-6
3	Report to the captain	No. 1 & 2 Tel	9-14, 4-1
4	Report to engine room and prepare pump	No. 1 & 2 Tel, Fire pump	9-14, 4-1, (16-9,16-10)
5	Report ship location to communication man. When necessary, send SOS signal	VHF, MF/HF	9-11, 9-12
6	With all available pumps, discharge sea water	Fire pump	16-9, 16-10
7	Implement temporary drainage by all possible means		
8	Implement sounding in all tanks and all areas.		
9	Measure draft	ECDIS	12
10	When necessary, implement arbitrary sinking	ECDIS, Chart	12, 2
11	Report to company and request help when necessary	Inmarsat F	4-1

situation, and it is multiplied by the configuration rate of maritime accident statistics(Table 1) and used as a weight value of the corresponding equipment on the actual performance of optimization.

2.2 Optimization

Among the respondents, the officer group was sub-categorized based on their job position and then a layout for each position was analyzed. The weighting for accident type used for optimizations is listed in Table 2.

The LINGO 8.0 Global Solver program was used in the optimization process to derive an ergonomic layout of navigational equipment.

The following are the symbols and variables used in the test.

Index

i : Equipment $(i=1,2,\cdots,n)$
j : Equipment $(j=1,2,\cdots,m)$
o_x : x coordinate at datum position
o_y : y coordinate at datum position

Decision Variables

d_{oi} : linear distance from the datum position to the centroid of equipment i
xl_i : x coordinate at lower right side of equipment i
yl_i : y coordinate at lower right side of equipment i
xr_i : x coordinate at upper left side of equipment i
yr_i : y coordinate at upper left side of equipment i
wc_i : x coordinate at the center of equipment i
vc_i : y coordinate at the center of equipment i

Constants

w_i : Width of equipment i
v_i : Height of equipment i
k_{ih} : Attribute score on item h of equipment i
bn_x : Width of bridge
bn_y : Height of bridge
a_i : Constant of emergency weight for equipment i

Objective Function

$$Min \quad \sum_{i=1}^{n} k_{ih} \cdot d_{oi}$$

$$Min \ ai \ \sum_{i=1}^{n} k_{ij} \cdot d_{oi}$$

(h = importance, usage frequency, voyage influence, possibility of operating and/or reading error) (1)

Objective Function (1) is an equation to minimize the distance from the datum position to the centroid of each item of equipment, in consideration of each item's attribute score for a specific item. For the attribute function, importance, usage frequency, influence on voyage, and possibility of error scores were obtained from the findings of the primitive survey on ship operators.

Constraint

$$d_{oi} = \sqrt{(o_x - wc_i)^2 + (o_y - vc_i)^2} \quad , \ \forall i \qquad (2)$$

Constraint (2) is an equation to calculate a linear distance from the datum position to the centroid of a specific item of equipment.

$$wc_i - xl_i = \frac{w_i}{2} \quad , \ \forall i \qquad (3)$$

$$vc_i - yl_i = \frac{v_i}{2} \quad , \ \forall i \qquad (4)$$

$$xr_i - xl_i = w_i \quad , \ \forall i \qquad (5)$$

$$yr_i - yl_i = v_i \quad , \ \forall i \qquad (6)$$

Equations (3) to (6) are designed to calculate (x, y) coordinations at the centroid point of each item of equipment.

$$(xr_i - xl_j) \times (yr_j - yl_i) \times (xl_i - xr_j) \times (yr_i - yl_j) > 0 \quad , \ \forall i,j \quad (i \neq j) \qquad (7)$$

Equation (7) above is a constraint to avoid any double count of any equipment.

$$xr_i \leqq bn_x \quad , \ \forall i$$
$$yr_i \leqq bn_y \quad , \ \forall i \qquad (8)$$

Equation (8) is a constraint to ensure that the layout does not exceed the range of the bridge's width and height.

$$xl_i \geqq 0 \quad , \ \forall i \qquad (9)$$

$$yl_i \geqq 0 \quad , \ \forall i \qquad (10)$$

$$xr_i \geqq 0 \quad , \ \forall i \qquad (11)$$

$$yr_i \geqq 0 \quad , \ \forall i \qquad (12)$$

Equation (9) to (12) are the constraints to ensure that the final suggestion of coordinate values are given in positive numbers.

3. Result

3.1 Optimization

The values obtained by multiplying the composition ratio of accidents and the accumulated number of times the related equipment has been used for an emergency situation, as well as the usability evaluation value for this item of equipment, were used to perform the final optimization.

The weighted values for other kinds of emergency situations were calculated in the same way, and during this process, the optimization of on-bridge navigational equipment was carried out.

Fig. 2 shows the results of the optimization.

Layout															
A. importance + usage frequency															
										▼ Datum point					
17	3	15	18	6	2	9	13	12	8	7	14	5	4	16	11
B. sum of evaluation score × (emergency weights)															
										▼ Datum point					
17	3	15	18	6	2	7	13	8	9	12	14	5	11	4	16

Fig. 2 Result of Layout of optimization

"A" shows the results of the optimization using scores based on the level of importance and usage frequency of the item of equipment.

The bridge in the training ship consists of a total of 18 panels, and the numbering system indicated in the tables represents the actual layout of navigational equipment on the Bridge.

"B", the Bridge model was drawn based on the optimization result with the emergency weights applied to the scores of importance, usage frequency, influence on voyage, and the possibility of operation and readout errors.

ECDIS(12) and VHF of GMDSS(9) were placed the nearest to the datum point, and this suggests that they need to be located nearest to the officer for operations.

3.2 Comparison and Analysis

The purpose here is to compare and analyze the final optimized layout (Fig. 4) and the existing layout. The moving distances were calculated and the efficiencies based on them were compared to predict the traffic lines of the operator when reading the control or display devices of the navigational equipment for ship operation. The Bridge model for the training ship has been used as the existing model in the research and the suggested optimal Bridge model after applying the ergonomic variables (Fig. 4) are shown. For comparison and evaluation, the distances between the items of navigational equipment were measured (Fig. 3).

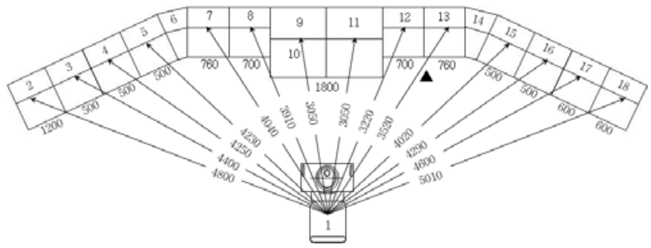

Fig. 3 The existing layout

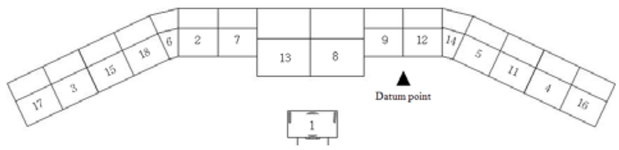

Fig. 4 Proposal layout

Table 5 suggests a checklist upon the ship's departure. The indicated numbers of navigational equipment, control and display devices correspond to the order of the checklist. The listed numbers on Table 4 were used as the numbers of navigational equipments.

For example, Navigational light control panel(7-3) and Signal light control panel(7-5) are the equipment to be used in the event of question 10, "the signal flags of departure is prepared and hoisted?". The Navigation light control panel and Signal light panel of the existing layout are located at panel 7. In this case, the calculated moving distance of the operator from datum point (▲) is 3,580mm. Therefore, according to the comparison and analysis between the existing and the optimized layouts, the operator's moving distance was reduced by 1,000mm and this is only 72.1% of the moving distance before optimization. Consequently, it shows an increased efficiency of 27.9%. If conducting the comparison and analysis on the navigational equipment with the same methods, the results show that the suggested layout in this research has reduced the moving distance of the operator by 18.5%.

Table 6 suggests a checklist upon a ship's arrival. The indicated numbers of navigational equipment, control and display devices correspond to the order of the checklist. The listed numbers on Table 3 were used as the numbers of navigational equipment.

For example, VHF(4-1) is the equipment to be used in the

Table 5 Checklist of departure sequence

	Departure sequence	Equipment	Distance(mm)		Rate (%)
			Existing	Optimized	
1	Navigation plan is established?	2,3,12	6,060	5,590	92.2
2	Necessary watercourse map is prepared?	2,3,12	6,060	5,590	92.2
3	Steering operation is checked? - main steering gear, sub auxiliary steering gear - check if rudder angle indicator matches - steering gear, joints, exterior status - alarm device at breakout	1,15-1, 15-2	3,220 4,020	3,220 4,250	100 105.7
4	Test drive of main engine is conducted?	9-1(M-E rpm indicator)	2050	350	17.1
5	Navigational equipments are testes and ready for use? (RADAR, ECDIS, AIS, GPS, COURSE RECORDER, ECHO SOUNDER, WHISTLE and DOPPLER LOG)	1, 3, 2, 5, 8, (9-11, 9-12, 9-17), (VHF, MF/HF, whistle), 11, 12, 13	14,775	18,230	123.4
6	Mooring facilities are test-driven and ready for use?				
7	Tuning between MAIN GYROCOMPASS and REPEATER is checked?				
8	Moving objects including boats, accommodation ladder, derrick and etc are secured at the ship body?				
9	The close/open status of each storage door and watertight sliding door is checked?	4-2(Watertight sliding door)	4,710	2,060	43.7
10	Signal flag of departure is prepared and hoisted?	7-3, 7-5	3,580	2,580	72.1
11	Take-off(departure) report is completed?	9-11(VHF)	2,050	350	17.1
12	Clean water, fuel and other necessary consumables are supplied?				
13	Repairs are finished for repair-necessary parts?				
14	All crew are on board?				
15	All persons to leave the ship are off the ship?				
16	Documents and certificates of main ship that were sent to the lang are collected?				
17	Vulnerable area is patrolled such as Bosun Store, (2 hours before the departure/1 hour before the departure/immediately after departure) to prevent stowaways on board?				
18	Parallel running of STEERING MOTOR is taken care of?	16-21(S-G alarm panel)	1,885	2,860	151.7
19	Binocular and DAY LIGHT SIGNAL are ready?				
Total			48,410	45,080	81.5

Table 6 Checklist of arrival sequence

	Departure sequence	Equipment	Distance(mm)		Rate (%)
			Existing	Optimized	
1	Navigation plan is established?	2, 3, 12	6,060	5,590	92.2
2	Necessary watercourse map is prepared?				
3	Steering operation is checked? - main steering gear, sub auxiliary steering gear - check if rudder angle indicator matches - steering gear, joints, exterior status - alarm device at breakout	1,15-1, 15-2	3,220 4,020	3,220 4,250	100 105.7
4	Test drive of main engine is conducted?	telegraph			
5	Navigational equipments are testes and ready for use? (RADAR, ECDIS, AIS, GPS, COURSE RECORDER, ECHO SOUNDER, WHISTLE and DOPPLER LOG)				
6	Mooring facilities are test-driven and ready for use?				
7	Communication devices such as Microphone and transceiver are tested?				
8	Mooring line, heaving line, rat guard and accommodation ladder are ready for use? (when necessary, prepare anchoring)				
9	Tuning between MAIN GYROCOMPASS and REPEATER is checked?	1(Gyro compass)	3220	3220	100
10	Notified at engine room before leaving the port?				
11	Signal flag of port entry is prepared and hoisted?				
12	Port entry report is completed?	9-11	2,050	350	17.1
13	Notified expected port entry time to inland agent?	4-1	4,710	2,060	43.7
14	Notification of ETA to PILOT STATION and PILOT LADDER is prepared?				
15	Tide tables are ready and the recent weather chart reception is completed?				
16	Port entry document is ready?				
17	Clocks at Bridge and engine room are matched and phone is tested?	(4-1, 9-14)(Auto Telephone)	4,710	2,410	51.2
18	Parallel running of STEERING MOTOR is taken care of?	16-21(SG alarm panel)	1,510	2,660	176.2
19	Binocular and DAY LIGHT SIGNAL are ready?				
Total			29,500	23,760	80.5

event of question 13, "Notified expected port entry time to inland agent". In this case, the calculated moving distance of the operator from the datum point (▲) is 4,710mm(Fig. 3). The VHF in the suggested layout is located at 2,060mm(Fig. 4). Therefore, according to the comparison and analysis between the existing and the optimized layouts, the operator's moving distance was reduced by 2,650mm and this is only 43.7% of the moving distance before optimization. Consequently, it shows an increased efficiency of 56.3%. If conducting the comparison and analysis on the navigational equipment with the same methods, the results show that the suggested layout in this research has reduced the moving distance of the operator by about 18.99%.

In conclusion, the suggested layout in this study has reduced the operator's moving distance by 19.5%, compared to the existing layout, and consequently, the reduced moving distance is expected to lower the possibility of human error among maritime accidents caused by the officer's reduced fatigue and rapid counter-responses.

4. Conclusion

The purpose of this research was to develop an optimized layout of a ship's navigational equipment on-Bridge, differently arranged according to the ship's size or type, with the consideration of ergonomic factors.

This research went further by suggesting a ship's ideal Bridge layout based on the importance and usage frequency of navigational equipment that was investigated during prior research, and conducted a usability evaluation on the importance and usage frequency of navigational equipment on the training ship's bridge, observing the degree of each piece of equipment's influence on navigation, and the possibility of operation or readout errors for the ship's officers. Optimization was performed using the Lingo program from the survey results. Optimization of on-Bridge navigational equipments was performed based on the primary questionnaire survey.

According to the comparison and analysis between the existing and the optimized layouts, the operator's moving distance was reduced. Consequently, the results show that the suggested layout in this research has reduced the moving distance of the operator by about 19% on situations of departure and arrival. Also, with the consideration of emergency situations, an optimized suggestion for a layout was derived with emergency- weight applied. It was suggested that ECDIS, Radar and Conning Displays should be located nearest to the officer. Also, an optimized design for panels of control and display devices on the Bridge was suggested in this research.

Also, the research proved through examples that the ergonomic layout, which was suggested by predicting the officer's traffic line upon a ship's departure or arrival, is more efficient than existing layouts.

As a plan to relieve a ship navigator's burden, this study attempted to suggest an ergonomic layout for on-bridge navigational equipment that plays an essential role for ship operations, and it is expected that the results of this study will be used as basic data in providing ergonomic guidelines in the shipbuilding and maritime fields.

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