Ergonomic ship bridge design supports minimum manning

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Abstract

The Royal Netherlands Navy is designing a new hydrographic survey vessel to replace the currently used vessels. A key issue concerning the design is the question whether a task extension of the Officer of the Watch could be achieved, reducing the required manning.

A task analysis has been carried out to investigate the possibility of the proposed task extension of the Officer of the Watch. Using results of existing research projects of TNO, we were able to predict whether the task extension was possible, and what design consequences had to be made to ensure safety and to overcome too high mental workload. These design consequences concerned the bridge design and instruments, as well as the organisation of the tasks. The ship bridge has been designed based on the existing models of the Royal Netherlands Navy. The design meets the consequences of the task extension, as well as constraints on anthropometry, outside view, construction, et cetera. The design includes the arrangement of workspace and the detailed design of workplaces. Digital human models were used to check the anthropometric qualities of the design and enables a fast and iterative design process. We anticipated the life-time of the vessel by modelling the expected user population in the year 2030. Using a virtual environment, officers were immersed into the design and were able to evaluate outside and inside view, as well as the spatial arrangement of workplaces and instruments. Results of the evaluations were used to improve the design.

Concluding, this project shows an ergonomic design process integrating a wide range of human factors knowledge. Using available results of research concerning task performance at ship bridges under several conditions, as well as modern design techniques and anthropometric databases, we were able to optimise the design of the ship bridge in order to meet the demand on minimum manning.
1 Introduction

The Royal Netherlands Navy is designing a new hydrographic survey vessel to replace the currently used vessels. The layout of the ship bridge and bridge wings, and the ergonomic workplace designs have been made by TNO Human Factors.

To create an ergonomic optimal bridge design, three steps were made. Firstly, a task analysis provided an answer to the question whether a task extension of the operators at the bridge could be achieved, reducing the required manning. Secondly, an ergonomic design of the bridge and bridge wings was made. And thirdly, the design was evaluated using digital human models and a virtual environment to improve the design. Of course, the sequence of these steps is not fixed; the design process is iterative.

This paper describes the procedure and the main results of this ergonomic design process that has been carried out in the first half of 2000. Details of this project are described by Punte et al. [1].

2 Task analysis

A key issue concerning the manning of the vessel was the question whether a task extension of the operators at the ship bridge, especially the Officer of the Watch, could be achieved. Because of the short time-span of this project, this question has been answered using existing results of research projects of TNO.

2.1 Mission of the vessel

The primary task of the vessel is to collect hydrographic data for civil as well as military purposes. Using these data, sea charts can be created or updated. To collect these data, the vessel will be equipped with a wide range of hydrographic sensors. Some of these sensors are positioned under the vessel, others are dragged behind the vessel. Data acquisition takes place while navigating on predefined tracks. The data acquisition will be monitored at the bridge. This is one of the tasks of the Officer of the Watch.

2.2 Function model

The Royal Netherlands Navy has made a function decomposition model that consists of all operational and supporting functions of the vessel. Functions that affect the activities of the operators at the bridge, are combined into a function model of the bridge of the vessel. The functions have been divided into four main categories:
- monitor and control travel: this main function contains all functions that are related to monitoring and controlling the travel and that have to be carried out at the bridge of the vessel. This function has been decomposed into monitor and control propulsion, navigation, and manoeuvring;
- monitor traffic: this main function consists of all functions that are related to monitoring surrounding traffic (for instance the fairway) of the vessel;
- monitor platform: this main function contains all functions that are related to monitoring platform, propulsion, steering, and emergency systems;
- monitor hydrography: this main function contains all functions that are related to the acquisition of hydrographic data, and to the typical hydrographic manoeuvring and navigation.

Figure 1 shows the four main functions and decompositions of some of these functions.

![Figure 1: A function model of the bridge of the hydrographic survey vessel.](image)

Under normal conditions, the functions shown in figure 1 have to be carried out by two operators at the bridge: the Officer of the Watch and the helmsman. The helmsman can also serve as an outlook. Compared to the existing hydrographic survey vessels of the Royal Netherlands Navy, the tasks of the Officer of the Watch and the helmsman will be extended in two ways. Firstly, the number of hydrographic sensors will be increased. Secondly, the platform monitoring function is completely new at the bridge. The reason for adding this function to the tasks of the bridge operators is to create an unmanned control room under normal conditions.

2.4 Task analysis and requirements

Based on experiences with the existing hydrographic survey vessels, it is known that the Officer of the Watch and the helmsman are able to handle the current tasks in a proper way. The main question is whether the proposed task extension, that is monitoring an increased number of sensors and the addition of platform monitoring, can still be handled by these two operators, under normal conditions, without creating a too high mental workload, and unsafe situations.

The reasoning strategy to investigate the task extension was based on the function model (figure 1). For each function it was determined, based on existing research, whether the task could be handled by the Officer of the Watch, assisted by the helmsman, and what requirements would be necessary to support the
operators. The requirements refer to the equipment and layout of the bridge, as well as to the allocation of tasks to personnel. This strategy started with the main function "monitor and control travel" and continued with "monitor traffic", "monitor hydrography", and, finally, "monitor platform". During the assessment of each function, it was decided whether the addition of the function to the previous ones could be handled by the Officer of the Watch, assisted by the helmsman. Besides, the list of requirements was extended with new requirements that resulted from the addition of the new function.

To clarify the strategy described above, the assessment of the last function "monitor platform" will be given as an example. This assessment succeeded the assessment of "monitor and control travel", "monitor traffic", and "monitor hydrography". As a result of these previous assessments, the requirements list consisted, amongst other things, of:

- alarms of hydrographical sensors have to be acoustical;
- optimal view to the rear of the ship on account of the 180 degrees course changes in hydrographical tracks;
- controls of the dragged sensors have to be within direct reach of the Officer of the Watch at his navigation position, and within direct reach of the helmsman at the conning position;
- hydrographic activities at the bridge have to be supervisory, otherwise the bridge team has to be extended with a hydrographic operator.

Based on research by Boer and Schuffel [2], Schuffel and Walraven [3], and Schuffel et al. [4], it was concluded that the platform monitoring function could only be added to the previous functions on the condition of a central information presentation using a cockpit layout at the navigation console. Furthermore, research by Gemen and Boer [5] indicated that platform monitoring could be added to the task when it would be a supervisory task, and an operator of the control room could be called up when the task is asking too much attention. Finally, according Van Breda and Passenier [6], and Van Breda [7] the addition of trial manoeuvres to the tactical navigation display prevents from too much deviation of the planned tracks after great course changes, which frequently appear during data acquisition.

As a result of the assessments of all functions in the function model, it was concluded that the task extension proposed would be possible when a set of requirements would be satisfied. These requirements affect the instruments, as well as the organisation of personnel at the bridge of the hydrographic survey vessel.

2.5 Critical scenarios

To test the completeness of the list of requirements derived, 10 scenarios were developed, that were used as a starting point for a discussion with experienced operators of the existing hydrographic vessels of the Royal Netherlands Navy. The scenarios varied in regard to the condition of the bottom of the sea, the traffic density, wind force, and sight. For each scenario, possible problems were discussed, and additional requirements were added to the list of requirements. In
critical situations, the Officer of the Watch and the helmsman will be assisted by other operators, i.e. the Commander of the ship, a hydrographical operator, and/or an operator of the control room. From the scenarios it appeared that under some condition, five operators have to be positioned at the navigation console at the same time. This was one of the additional requirements that was derived from the discussions with the experienced operators.

3 Bridge design

Based on the task analysis it was concluded that the task extension proposed is possible when several design requirements are met. Besides, other sets of requirements had to be integrated into the design of the bridge and bridge wings of the hydrographic survey vessel:

- the design of the ship hull and the shape of the bridge, delivered by the Royal Netherlands Navy;
- the inventory of all instruments that had to be positioned at the bridge or bridge wings, delivered by TNO in co-operation with the Royal Netherlands Navy;
- the ergonomic requirements that were put forward by TNO itself. These requirements can be divided into ergonomic requirements concerning the layout of the bridge (accessibility, safety, outside view, et cetera), workplace design (sitting and standing comfort, reachability, visibility, and readability of instruments and displays, et cetera), and work environment (lighting, sound, vibrations, et cetera).

These requirements are integrated in the design of the bridge and the bridge wings. As part of this design process, various departments of the Royal Netherlands Navy participated in the design sessions. During these sessions, Computer Aided Design (CAD) models of the bridge were discussed and improved. We made use of the CAD-tool ProEngineer and two SmartBoards to present the design during these sessions.

The final detailed ergonomic design of the ship bridge and the bridge wings consisted of the layout of the bridge, the ergonomic design of the workplaces, and requirements that are related to the working conditions at the ship bridge. In the remaining part of this section, the layout of the bridge and the ergonomic design of the navigation console will be discussed briefly.

Figure 2 shows the layout of the bridge and bridge wings of the hydrographic survey vessel. In this model, the roof has been removed to enable a view into the bridge. The geometry of the bridge optimises the outside view, both when standing and sitting behind the navigation console. Special attention has been paid to the outside view at the rear of the vessel because of the 180 degrees course changes during navigation on hydrographical tracks.

Figure 3 shows the navigation console that is positioned at the front of the bridge. The second chair from the right is the workplace of the Officer of the Watch. The instruments that are necessary to carry out his tasks are positioned in a cockpit layout around this workplace.
Figure 2: Layout of the bridge of the hydrographic survey vessel.

Figure 3: Workplace design of the navigation console of the hydrographic survey vessel.
The starting points for design were the application of the Electronic Chart Display and Information System (ECDIS), and the Automatic Radar Plotting Aid (ARPA). Both displays are positioned in front of the Officer of the Watch. At the left side of the Officer of the Watch (at the centre of the navigation console) several manoeuvring instruments and the conning display are positioned. These are also reachable by the helmsman. At the right side of the Officer of the Watch, hydrographic instruments and a display for maintaining platform are located.

The left side of the navigation console consists of a redundant workplace (this is the fourth position from the right). This is also the position where the Commander can stand or sit. Also, two displays for maintaining platform are located at the left wing of the navigation console. At this position an operator of the control room can assist the Officer of the Watch during calamities.

4 Evaluation

The ergonomic qualities of the design have been evaluated as part of the design process. For this evaluation we used two techniques. Firstly, digital human models were used to judge ergonomic qualities of the workplaces. Secondly, a virtual environment was used to evaluate outside and inside view, as well as the spatial arrangement of workplaces and instruments. On the basis of the results of both evaluations, the design was improved.

4.1 Digital human models

Digital human models were used to check the anthropometric qualities of the workplaces at the bridge, especially the navigation console. The design of the workplaces were exported from the CAD-tool ProEngineer into the Boeing Human Modeling System (BHMS) to carry out the evaluation.

Before the evaluation starts, a set of digital humans, the so-called manikins, were defined, representing the future user population. This population consisted of male as well as female users from the Netherlands, between 18 and 65 years of age. We anticipated the life-time of the vessel by using the current anthropometric characteristics of this population, as well as the expected anthropometric characteristics in the year 2030. These are based on an expected secular growth of the male population of 1.6 mm a year, and an expected secular growth of the female population of 0.9 mm a year (Burgmeijer & Van Wieringen [8]). Furthermore, a shrinkage of 0.83 mm per year for each individual between the age of 45 and 65 was taken into account (Molenbroek [9]). The lower boundary of the user population was the fifth percentile female user with a stature of 1.67 m. The upper boundary of the user population was the ninety-fifth percentile male user with a stature of 1.97 m.

The evaluated aspects of the navigation console using the digital human models were:

- sitting and standing comfort behind the navigation console;
- the possibility of using the navigation console by five operators at the same time;
the reachability and visibility of instruments and displays;
- the outside view over the rim of the navigation console.

Figure 3 shows a part of the navigation console with two digital human models. The manikin at the left side is positioned at the chair of the Officer of the Watch. The manikin at the right side is standing at the position of the hydrographic operator.

Figure 4: Evaluation of the navigation console of the hydrographic survey vessel using the human modelling system BHMS.

Using the results of this evaluation, the outside view at the helmsman position was improved by lowering the rim at the centre of the navigation console. Also, it was concluded that the navigation console indeed can be used simultaneously by five operators without hindering their standing or sitting comfort. Furthermore, in standing position all instruments are reachable by the Officer of the Watch, while in sitting position the most important instrument are reachable by the Officer of the Watch.

4.2 Virtual environment

The second evaluation of the bridge design was the application of a virtual environment. Virtual environments are suitable to draw the current users of the hydrographic survey vessels into the design process. The virtual environment consisted of the hydrographic survey vessel itself, a marine environment, and several other ships around. The model of the ship was made by combining the CAD model of the bridge, delivered by TNO, and the CAD model of the ship hull that was delivered by the Royal Netherlands Navy.

A virtual environment system enables an operator to interact immersively with a three-dimensional computer-generated environment. Computer graphics are presented through a head-mounted display (HMD) positioned just in front of
the eyes. Head movements are recorded continuously in order to present the correct image with a fast update rate.

Using the virtual environment, three officers of the Royal Netherlands Navy were immersed into the design and were able to evaluate outside and inside view, as well as the spatial arrangement of workplaces and instruments. All subjects were experienced officers of the existing hydrographic survey vessels.

During the evaluation, a scenario was carried out that consisted of unmooring, travelling at open sea, including some 180 degree turns at the end of hydrographic tracks, and mooring. Questionnaires were used to evaluate the inside and outside view of the bridge, and the arrangement of workplaces and instruments. During the scenarios, the eye height and the position of the subjects at the bridge were varied. Figure 5 shows a subject wearing the HMD, as well as the inside and outside view standing at the left side of the navigation console in the virtual environment of the hydrographic survey vessel.

![Figure 5: One of the subjects wearing an HMD, the picture at the left is one of the images that is shown at the HMD.](image)

Using the results of the virtual environment evaluation, the outside view from the bridge to the rear of the vessel was improved by moving a staircase, and lowering the number of roof supporting columns inside the bridge. Also, the layout of the bridge wings was improved to optimise to view to the decks and the waterline beside to the vessel.

### 5 Conclusions

This project shows an ergonomic design process in which a wide range of knowledge has been integrated. A ship bridge, including bridge wings, has been designed for the hydrographic survey vessel of the Royal Netherlands Navy, meeting all requirements and supporting minimum manning.

Using available results of research concerning task performance at ship bridges under several conditions, we were able to predict whether a task extension was possible for the operators at the bridge, the Officer of the Watch in particular. As a result of the assessments of all functions in the function model, it
was concluded that this task extension was possible when a set of requirements were satisfied. These requirements affected the instruments, as well as the organisation of personnel at the bridge of the hydrographic survey vessel.

Thereafter, the design itself was made using modern design techniques and anthropometric databases. Visualization of a design stimulated the exchange of information between designers, (future) operators, and customers very early in the design process. Virtual environment techniques made it possible to situate the bridge and the vessel in a realistic scenery, and to evaluate inside and outside view. Using the digital human models, it was possible to take into account the anthropometric extremes, including subjects to be expected as crew members in the year 2030. The application of these techniques reduced time-to-market and costs during the design process, as compared to the traditional design process that, usually includes a series of wooden mock-ups.

References


