Development of a Concept for Ergonomic Design and Work Organization of Remote Lock Operation Centers

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ABSTRACT

A trend can be observed towards grouping and shifting local operations to centralized remote lock operation centers (RLOCs) due to costs and limitations in personnel resources and the increasing automation level of technical systems. However, safety-critical activities still require active monitoring of processes by a human operator with help of adequate technical systems and interfaces. Therefore, many video images and abstract representations must be shown simultaneously at one workplace to guarantee an all-inclusive overview. Given this situation, it has to be determined from an ergonomic point of view how many systems (e.g. lock chambers) can be controlled by one operator. Therefore, the challenge is to develop a new efficient and ergonomic control concept for RLOCs that prevents straining work conditions in terms of mental over- and underload. This control concept should enable the short-term and situation-dependent allocation of systems to operators. Moreover, prospective personnel resource planning and the design of the control panels have to be adapted to the control concept and human performance factors.

The following paper presents a study covering the analysis of tasks and processes in remote lock operation centers around Germany including soft- and hardware design components in use. Based on the results, a new concept integrating ergonomic requirements for remote control and monitoring has been developed. This concept enables the assignment of optimal workload to one workplace by determining the potential straining condition within one shift. For the purpose of integrating prospective and retrospective evaluation, a practical guide for personnel management and scheduling has been developed. It includes a questionnaire and calculation specifications that can be generically adapted to other remote operation centers. In addition to the strain which is evoked by the main tasks of lock control and monitoring, it also considers the impact of additional tasks. Based on the developed concept for remote control and monitoring and in accordance with the assessed ergonomic design requirements, the control panel layout has been determined with regard to anthropometric dimensions.

Keywords: Ergonomic Design, Remote Operation Centers, Lock Operation, Control Panel, Personnel Management, Usability

INTRODUCTION

Since advances in process control engineering enable to operate even safety-critical systems remotely, an automation of systems and centralized control and monitoring processes in RLOC can be observed in Germany. This trend affects the process control level in terms of higher degree of automation and digitalization of the work system (e.g. Ivergard and Hunt, 2008; Stanton et al., 2010) and consequently evokes various changes in the sociotechnical work system (DIN EN ISO 6385, 2004). Due to the higher automation, steps which prior to this trend were executed manually by the operator are now omitted. However, for safety-critical processes, there is still a need to actively initiate and monitor a process by a human operator. Therefore, grouping and shifting local operations to centralized RLOCs represents a solution that leads to more efficient use of personnel resources but is also accompanied by new challenges in work space design and work organization.

At the beginning of the 2000s, the organization of lock operation changed from on-site control to remote control and monitoring in Germany. Several technical systems are connected with the RLOCs and can be remote controlled by the operators via a computer interface. These systems include lock chambers, weirs, pumping stations, flood barrages, light-signal systems and bridges. Until 2012, 27 RLOCs were built across Germany with 113 connected lock chambers plus other systems. In the next few years, it is planned to establish 33 RLOCs with 172 connected lock chambers. However, no standard for ergonomic design and work organization has been established yet, rather a series of regional solutions can be found.

This paper focuses on the consequence of this trend regarding ergonomic issues such as work environment, work place and human-system interaction on the one hand and organizational aspects as allocation of system(s) to operator and personnel resources on the other hand. One challenge in this context, for example, is the simultaneous depiction of a lot of information (video images and abstract schemas of the control interface) at one workplace. This results in a high number of monitors and is often insufficiently implemented regarding ergonomic criteria. Hence, the aim of this paper is to develop solutions for the ergonomic challenges evoked by remote lock control. As a result, a concept for an ergonomic design and work organization is presented.

METHODOLOGICAL APPROACH

The aim of this study was to develop an ergonomic design and work organization concept for RLOCs in Germany. Therefore, a two-stage methodology was developed consisting of an analysis of the current state and the development of recommendations in terms of a concept for RLOCs (Figure 1).

Within the first stage – the analysis of the current state – several aspects were differentiated: analysis of the work process, an ergonomic analysis of physical and environmental conditions and an ergonomic analysis of human-system interaction. The analysis of the work process also included factors that influence the work process in a technical and organizational sense. The analysis of the current state was conducted for a sample of 14 RLOCs in Germany and covers process monitoring for different shifts (morning, evening, night) and interviews with 42 operators. The analysis of the current state is described in the section analysis of the current state of this paper (1.work process, 2.physical and environmental ergonomics, 3.ergonomics of the human-system interaction).

The analysis of the current state allowed the identification of deficits and with respect to the ergonomic design enabled to derive design recommendations for RLOCs. As a part of these recommendations we propose a comprehensive concept for ergonomic design and work organization of RLOCs. According to the derived work process and the determining factors, first, an ergonomic concept for remote control and monitoring was developed consisting of four cases depending on the traffic volume. Second, this concept served as a basis for the suggestion of a guide for personnel management and scheduling. This guide is in turn used to determine which case of the developed concept for remote control and monitoring has to be applied. Third, an ergonomic control panel was designed based on the ergonomic recommendations for the work place and the ergonomic concept for remote control and monitoring. Furthermore, design recommendations were derived regarding the work environment and the design of the Graphical User Interface (GUI). Some examples of these recommendations are given in the design recommendation section.

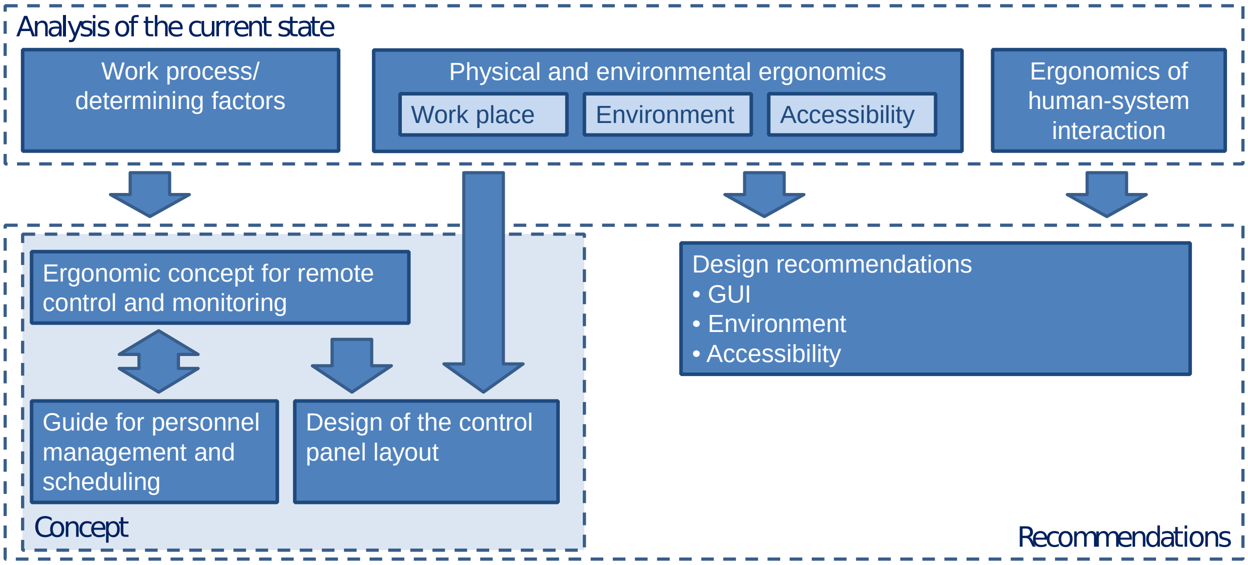


Figure 1: Methodological approach

ANALYSIS OF THE CURRENT STATE

The first step in the development process of a concept for ergonomic design and work organization of RLOCs was an investigation of the current state. This investigation involved an analysis of the work process including the specification of determining factors and the classification of main and additional tasks. Furthermore, relevant ergonomic criteria were derived from respective ISO standards and guidelines and were adapted to the practical context.

Analysis of the work process and determining factors

(a) Method

First, a workshop was conducted with representatives of all stakeholders to collect and map all occurring processes and classify them into main and additional tasks. Furthermore, information about determining factors, restrictions and special characteristics of the systems was collected. An iterative procedure based on participants’ feedback in different RLOCs was chosen for modeling all main tasks. For additional tasks a similar approach was taken as all occurring tasks were collected and classified. Information about frequency, duration and the possibility to conduct the task in parallel to a main task was added.

Second, a process observation was carried out to verify the results of the workshop. Additionally, the Rating Scale Mental Effort (RSME) (Zijlstra, 1993) was used to analyze the short-term mental effort which is evoked by executing occurring tasks. The operators were instructed to rate their mental effort every 15 minutes during one shift on a scale between 0 and 150. The results were matched with the tasks that were carried out by the operator in the corresponding 15 minutes.

(b) Results

Main tasks that occur within remote lock operation centers in Germany include all operations and tasks that are directly related to the lock operation or monitoring process, e.g. gate control, light-signal control, monitoring of the gate movements and the water level adjustment in the lock chamber. For the main tasks a meta-process-model was derived integrating several variants for safety systems, light-signal and gate control as the main processes are not identical in all remote lock operation centers and depend highly on the given technical conditions. The lock operation is executed remotely via control software using a mouse as input device. The implementation of the GUI of the control software also differs between the investigated RLOCs. Regarding the allocation of system(s) to operator, different variants exist but currently no consistent solution has been implemented for RLOCs in Germany. The monitoring process is supported in average by seven video images per lock chamber. These video images depict the current state of the lock chamber in a sequence from the upper to the lower side of the lock chamber. When a ship that accesses the chamber is monitored the operator has to observe adjacent monitors.

Additional tasks include for example telephone or radio information and guidance, administrative tasks such as traffic management and additional tasks that have to be executed at high watermark.

Regarding the short-term mental effort, the analysis revealed that long-running processes lead to subjectively higher mental effort for the operators than short processes which can be interrupted. In addition, for processes that occur in parallel or in blocks a higher mental-effort was recorded.

Physical and Environmental Ergonomics

(a) Method

For the ergonomic evaluation of the physical and environmental factors an approach consisting of two parts – an expert review with a checklist and a user interview – was adopted. The checklist was developed based on established standards and guidelines (DIN EN ISO 9241-6, 2001; DIN EN ISO 7726, 2002; DIN EN ISO 11064-5, 2008; DIN EN ISO 9241-303, 2011; DGUV: BGR 131-1, 2008; VBG: BGI 7003, 2008; VBG: BGI 5128, 2008; Probst, 2003) and adopted to RLOCs. It is divided into three main categories: (1) “work environment”, (2) “workplace and posture” and (3) “accessibility”. The first category includes items regarding the environment e.g. climate or illumination in RLOCs. Examples of items in this category are:

- Minimal illuminance is ensured (500 lx for work area, 300 lx for surrounding areas)
- Brightness distribution is adjustable
- Direct and reflected glare is limited
- Interior temperature is adjustable and between 23°C and 26°C in summer and 19°C and 24°C in winter
- Interior humidity lies between 40 and 65%
- Outdoor air supply is provided
- Noise emissions are reduced to a maximum of 55dB(A)

The second category focuses on the design of the workplace, e.g. screens, control panels and work seats. Example items are:

- Viewing distance to video monitors is between 500 mm and 1500 mm
- Viewing distance to several monitors is as constant as possible
- Minimum size of video monitors (minimum 15’’) is ensured
- Monitors are arranged within the vertical ergonomic field of view (0°-30° underneath the horizontal)
- Monitors are arranged within the horizontal field of view (0°-45° to each direction)
- Glare and reflection on monitors are prevented
- Minimal depth of the working desk (800 mm) is ensured

The last category deals with accessibility of the operation center for physically disabled people, e.g.:

- Work place is accessible for physically disabled people
- Bathroom for handicapped is installed

In order to receive an overall view of the ergonomic situation the subjective perception of the operators was recorded with user interviews. The interviews focused for example on ergonomic aspects that vary over the year (climate, illuminance) and aspects which were difficult to observe objectively (e.g. difficulties to match acoustical signals).

(b) Results

Regarding the ergonomic design, the investigated RLOCs show mainly positive results. Within the category “work environment” 74%, in category “workplace” 66% and in category “accessibility” 44% of the items were fulfilled in average. Most of the ergonomic deficits are due to the establishment of RLOCs in old lock buildings as for example lock towers. These buildings often have large windows and a multi-story architecture without elevators. For on-site lock operation a sufficient view on the lock chamber is guaranteed by this architecture but computer work is affected negatively by large windows (e.g. contrast ration between screen and background, glare).

Ergonomics of the Human-System Interaction

The work system in RLOCs consists of a software system that enables to control several technical subsystems remotely. The interface of this control software is realized via a GUI. Aim of this part of the investigation was to analyze and evaluate the usability of the different GUIs which are applied in the investigated RLOCs.

(a) Method

For the evaluation of the GUI of the control software an expert-review with a checklist based on guidelines, directives and standards (DIN EN ISO 9241-110, 2006; DIN EN ISO 9241-303, 2011; DIN EN ISO 11064-5, 2008; MIL-STD-1472D, 1994; O´Hara et al., 1994; Smith and Mosier, 1986; Widdel and Motz, 2002) was conducted. The checklist is divided into seven categories, (1) the “representation of information”, (2) “text and input formats”, (3) “display elements (characters, icons, scales)”, (4) “codes”, (5) “disorders”, (6) “process, redundancy and information requirements” and (7) “system support/learnability and safety”. Each category includes 5 to 28 items. Examples of items are:

- The required minimum font size is at least 16 arc minutes
- The GUI gives a schematic representation of the reality
- All information needed for a process is depicted on the GUI at that time
- Icons are similar to the objects/processes they represent
- Alarm and error-messages are in the front layer
- Mouse-over effect for functions gives detailed information

(b) Results

For the categories “representation of information”, “text and input formats”, “display elements” and “process, redundancy and information” 80% of the items were fulfilled in average. The items in the categories “disorders” and “system support/learnability” were only fulfilled to 64% and 51% in the investigated RLOCs. The category with the highest amount of fulfilled items is the category “codes” (94%). Altogether, none of the investigated GUIs had strong ergonomic deficits but neither fulfilled all investigated criteria.

CONCEPT

Ergonomic Concept for Remote Control and Monitoring

In order to enhance efficient work processes and develop systems that are robust against errors an ergonomic concept for remote control and monitoring was developed. This concept aimed at preventing mental over- and under load of the operators and is based on the traffic volume/condition of each system (e.g. lock chamber). Therefore, a categorization depending on the traffic volume into low-, average- and high-traffic volume systems was conducted. For high-traffic volume systems a 2:1 allocation of systems to operator is needed whereas for average-traffic volume systems a 4:1 allocation and for low-traffic volume systems a n:1 allocation of systems to operator is recommended. In addition for systems where high-risk operations occur in a high-frequency a 1:1 allocation of system to operator is suggested. It is furthermore assumed that each operator is responsible for all incoming operations at one workplace at a time. The allocation concept can vary for different workplaces within one RLOC.

(a) High-traffic volume systems (2:1 system to operator allocation)

For systems that are frequented by high-traffic a two-to-one allocation in which two systems are controlled/monitored by one operator is recommended. In this case the concept should ensure a permanent visualization of all relevant information in a symmetrical spatial arrangement to the left and to the right of the operator. Due to the stationary permanent visualization of all components of the two systems the error probability caused by confounding can be minimized. The operator is informed about the current status at any time. This supports the prospective planning of process operations. Furthermore, strain can be reduced actively because all relevant Information that is important for the decision process is directly accessible (Pashler, 1994).

(b) Average-traffic volume systems (4:1 system to operator allocation)

Average-traffic volume systems have a normal traffic volume that is (relatively) uniformly distributed within one shift and allow the operator to be responsible for up to four systems including the workload of incoming additional tasks. In this case we recommend a hybrid control and monitoring concept which consists of two control panels that are symmetrically arranged to the left and to the right of the operator. Each control panel displays one system at a time and allows switching between two systems. This concept enables the operator to control two systems in parallel which can be selected via a corresponding switching element and presents an upper limit for concurrent operations (Müller-Jung, 2010). Two systems are assigned permanently to one control panel and allow no switching between the two panels, which in turn reduces possible confusion. Furthermore, switching between the systems is only allowed via the switching element on the corresponding control panel. This minimizes the “costs of switching” (Monsell, 2003). Due to only binary transitions between systems, the deficits that occur for free assignment (conformity with user expectations, suitability for learning) can be reduced.

Error tolerant controlling/monitoring is supported by the permanent assignment of a process to whether the right or left side of the workplace within one shift. This hybrid concept guarantees that one operator can only control two processes in parallel. Ongoing processes that are switched to the background and are not visible any more are automatically brought to a save state by the system (corresponding to the emergency stop described in DIN EN ISO 13850 [2008]) as far as a continuous monitoring is necessary.

(c) Low-traffic volume systems (n:1 system to operator allocation)

Low-traffic volume systems require only little time for controlling/monitoring within a shift, for example during night shift when the traffic volume is at a low level. In this case one operator can be responsible for more than four systems. For operation hours with low workload of main and additional tasks a concept is recommended that allows allocating any number of systems to one operator. However, this concept involves certain limitations compared to the other concepts in order to ensure a process that prevents errors. To avoid confusion each operator is only allowed controlling one process at a time. Therefore the workplace consists of one control panel which visualizes exactly one system at a time. Concentration on solely one work process guarantees a sufficient conformity with user expectations during the control process despite multiple systems (Trouvain, 2008). Basic requirement for this solution is that the control and monitor operations are uniformly distributed within one shift and do not occur simultaneously. The application of this concept is not recommended when the workload is low but occurs simultaneously in blocks. In this case, the limitation of controlling no more than one system at a time would lead to a reduced efficiency and a temporally high strain of the operator.

(d) High-risk operations that occur in a high-frequency (1:1 system to operator allocation)

For high-risk operations, which allow no parallel processing due to high workload or the case that events emerge unpredictably and in blocks, a one-to-one allocation of system to operator is required. In this case a concept that allows only visualizing one system at one workplace is recommended. As a result, all required information is visible at any time and the attention does not have to be divided between several operations (Wickens, 1984). This case is only being listed for reasons of completeness and should be considered as an option when designing similar systems.

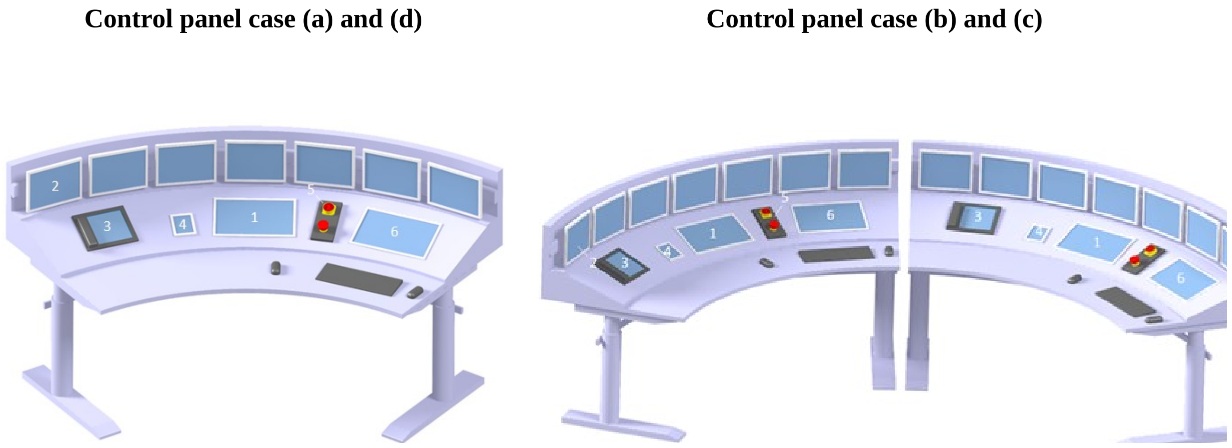
Design of the Control Panel

Based on assessed requirements and with regard to anthropometric dimensions a concept for the control panel layout was determined. Regarding the ergonomic requirements (e.g. maximum viewing distances, viewing angle) it is advisable to keep the number of monitors which are arranged at the control panel as low as possible. Based on the developed recommendations for the remote control and monitoring concept the representation of one system per control panel is preferred. Therefore, two control panels are needed for high-traffic volume systems: one operator controls two systems) and average-traffic volume systems: one operator is in charge of three to four systems as a maximum). For high-traffic volume systems (a one-to-one assignment between systems and control panels is needed whereas in the case of average-traffic volume systems (two systems are assigned to each of the two control panels. Low-traffic volume systems (one operator is in charge of more than four systems but does not control these in parallel) require only one control panel per operator. This control panel enables to operate any number of systems sequentially by remote control but only allows controlling of one system at a time. Switching between the systems is realized via a separate switching element. Therefore, a touch screen solution seems beneficial that allows switching between the systems as well as a visualization of the active systems. Furthermore, this switching element can be used to display the state of the respective lock chamber (e.g. via arrows) and to integrate a zoom-function for the camera.

In general, vertical adjustability of the control panel by the operator has to be guaranteed to enable the alternation of sitting and standing postures. 800 mm were chosen for the depth of the control panel in order to comply with the requirements. As the majority of considered lock chambers require displaying seven video images per system, this results in a high amount of monitors arranged at a control panel (7 video monitors, 1 control monitor, 1 traffic management monitor) and contradicts the realization of all ergonomic criteria. However, since a reduction of the video images that are displayed permanently is accompanied by an information deficit, the number of the displayed video images per lock chamber and thus per control panel was kept at seven video images. For each of the seven video monitors a minimum size of 15’’ was chosen, whereas for the control monitor and the traffic management monitor a larger size (e.g. 22‘‘-Widescreen) is recommended in order to depict more detailed information and to meet the required minimum of angular font size.

Regarding the monitor arrangement several options were considered. One option is to arrange all nine monitors in a row with a centered control monitor and a traffic management monitor. An argument against this arrangement is the violation of the maximum viewing distance for the external monitors. Furthermore, the arrangement of the control monitor and the traffic management monitor in between the video monitors would lead to a spatial separation of the video images. Another option is to position the control monitor and the traffic management monitor in front of the video monitors, however, for this arrangement the video monitors would be masked by the control monitor and traffic management monitor. A further option is a monitor arrangement in two rows, but since it is not possible to arrange all monitors within the vertical ergonomic field of view (0°-30° underneath the horizontal) (Schlick et al., 2010) it does also not provide a sufficient solution. As an alternative we recommend to arrange all 7 video monitors in a row underneath the horizontal visual axis and to position the control monitor as well as the traffic management monitor on a 20°-sloped board in the control panel (Figure 2). The two monitors arranged on the sloped board are adjustable regarding the inclination in order to prevent glare. The vertical angle of view on the control monitor measures for this arrangement between 19.4° (5. percentile women) and 29.7° (95. percentile man) and therefore fulfills the ergonomic requirements. The vertical angle of view on the video monitors measures between 4.3° (5. percentile women, regarding the external video monitors with the highest viewing distance) and 17.2° (95. percentile man, regarding the centre video monitor with the lowest viewing distance). It has to be mentioned that, since a movement of the operator is assumed, there is always a certain variability of the viewing angle.

Due to the high amount of monitors that need to be observed, it is not possible to arrange all video monitors of a control panel within the required maximum viewing distance in the horizontal field of view (45°). Therefore, the extended field of view (Schlick et al., 2010) with an angle of 70° served as a constraint. The viewing distance to the video monitors amounts between 980 mm (due to the required depth of the panel) and 1400 mm (in compliance with the maximum viewing distance). This results in a curvature radius of the table plate of R=2267.04 mm. Unfortunately, larger differences in the viewing distances between the different video monitors have to be accepted, but there is no solution that meets all ergonomic criteria for the requested length of the monitor row. However, since only adjacent monitors are observed and a moveable chair is required, this criterion can be neglected for the design.



Control panel case (a) and (d)

Control panel case (b) and (c)

1 – Control Monitor
2 – Video monitor
3 – Nautical information radio
4 – Touch screen element for switching
5 – Safety-stop
6 – Traffic management monitor

Figure 2: Three-dimensional model of the workplace for cases (a) and (d) [left] and (b) and (c) [right].

The control monitor and the traffic management monitor are arranged on the sloped board with a distance of 601.7 mm to the front edge of the panel. In doing so, a viewing distance larger than the required minimum viewing distance of 500 mm is also ensured for these monitors. The control monitor that depicts the GUI is needed for the main task of lock control and therefore arranged in the center of the panel. The traffic management monitor is needed for additional tasks (e.g. register ships that have been locked) and arranged in the right part of the panel. The board also serves to arrange the device for safety-stop (emergency stop and lock stop), the nautical information radio and the touch screen element. These devices usually require just grasping or reaching movements or only a short switching and thus can be arranged on the board in a control panel area distal from the body. The sloped board facilitates the grasping motion. For the lock control which is conducted via the control monitor no keyboard input is required and the mouse serves as sole input-device. For the traffic management text-input is required and therefore a mouse and a keyboard are needed. The input devices are arranged in the primary grasping area close to the respective monitors (Figure 2).

For high-traffic volume systems and average-traffic volume systems the workplace for an operator consists of two control panels which are arranged next to each other with preferably low distance in between (Figure 2). In the case of low-traffic volume systems and high-risks operations that occur in a high frequency, however, one control panel is sufficient. The relevant measures for the ergonomic design of the control panel are specified in figure 3.

An important component of the human systems integration plan should be a verification and validation process that provides a clear way to evaluate the success of human systems integration. The human systems integration team should develop a test plan that can easily be incorporated into the systems engineering test plan. The effectiveness and performance of the human in the system needs to be validated as part of the overall system. It may seem more attractive to have stand-alone testing for human systems integration to show how the user interacts with controls or displays, how the user performs on a specific task. This methodology can address the performance of the human operator or maintainer with respect to the overall system. The most important thing is to develop a close relationship between human systems integration and systems engineering.

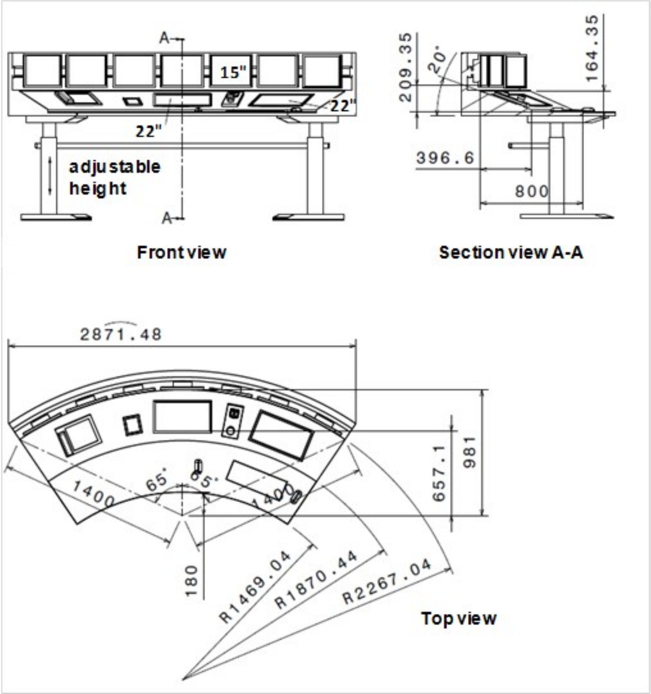


Figure 3: Measurements for the ergonomic design of the control panel

Guide for personnel management and scheduling

According to the introduced control and monitoring concept an approach for personnel resource planning and scheduling is proposed that not only integrates the strain evoked by main tasks but also considers the impact of additional tasks.

In order to obtain an objective quantification of the workload, a method based on statistical analysis of traffic data and standardized questionnaires was applied. Based on operation journals, system logs or statistics, the workload due to the main tasks has to be determined. Furthermore, the workload evoked by additional tasks has to be identified via information about the frequency of occurrence and duration of each individual additional task. This ensures a valid basis for the required prospective personnel management and scheduling. The determination of the cumulative workload is always conducted for a specified period within which a continuous or homogenous workload is expected (e.g. for one shift). This allows an application of the results to all periods with similar conditions. Aim of these determinations is to model the impact of different concepts on the workload as well as the efficiency of the remote lock operation center. Based on the results the most suitable constellation can be chosen

(a) Main tasks

First, the personnel which are required to manage the workload of the main tasks have to be estimated. Therefore, the time for the main tasks is evaluated and accumulated for each operator considering the respective control concept. This allows monitoring the workload for the entire RLOC regarding the temporal resources and monitoring the workload of each operator according to the individual conditions. It has to be considered that parallel processing is allowed for the 2:1 allocation and the 4:1 allocation and therefore a correction factor has to be integrated for the calculation for each operator to avoid a worst-case-estimation.

This correction factor (percentage of parallel tasks) can be calculated retrospectively based on statistics or determined via estimation and is multiplied by the total time and subtracted from it. To estimate the probability of temporal parallelism, the accumulated duration for each task has to be detected and put into relation to the investigated time period in order to determine the percentage of the respective time period. Subsequently, these values are multiplied for all tasks one operator is responsible for in order to receive the probability of parallel activities (Bortz, 1993. The multiplication of the probability of parallel tasks with the total duration of the main tasks results in the corrected value for the required time for main tasks.

(b) Additional tasks

Furthermore, the required personnel due to additional tasks have to be considered. Therefore, it has to be differentiated between additional tasks that can be carried out in parallel to main tasks and additional tasks that do not allow parallel processing. Tasks which can be carried out in parallel need to be taken into account in terms of higher strain for the operator, but do normally not require additional personnel resources as the required time for the additional tasks per shift is normally smaller than the total working time minus the calculated time for the main tasks. Resources for additional tasks that do not allow parallel processing need to be included and added to the required personnel resources calculated for the main tasks. Additional tasks that occur in blocks afford a separate determination of the required personnel for the respective time period. For the quantitative analysis of the additional tasks for a specified time period for one RLOC a questionnaire was developed. The questionnaire addresses issues such as frequency of additional tasks, duration of tasks, and parallel operation to main tasks.

Based on the identified task profiles, the workload and amount of operators can be modeled mathematically for each control concept. Furthermore, the straining condition that occurs for each operator can be estimated for each constellation. As a result, the most suitable constellation which leads to an ergonomic, optimal loaded and economic work for the operator can be established.

DESIGN RECOMMENDATIONS

Based on the investigations we were able to derive generic design recommendations for RLOCs. As it is not possible to provide a comprehensive overview in this paper, only some of the most important recommendations are summarized exemplarily.

Concerning the environmental ergonomic design and under consideration of the detected deficits in the operation centers, we among others recommend:

- Ventilation with external air
- Equal distributed illumination
- Glare shields
- Better accessibility for physically disabled people
- Ergonomic seats

Regarding the GUI of the control software we recommend for instance:

- Standardization of the GUI to facilitate the learning process and reduce errors when rotating between different RLOCs (especially important for safety-critical operations)
- An automatic prioritization of error-reports by the software system in order to facilitate the decision process of the operator and reduce strain.

In figure 4 the GUI for the lock control is shown exemplarily. Essential elements that need to be depicted are the lock chamber, gates, paddles and signals. These elements should give a schematic illustration of the respective lock system. This example depicts a lock chamber with two mitre gates and ground paddles (culverts). All elements that move (gates and paddles) need to be highlighted when moving as well as the arrow which indicates that a locking is operating and the direction of the locking (e.g. blinking). All values that need to be monitored are labeled and arranged close to the respective elements to prevent confusion. If relative values need to be monitored as for example the difference between the water level in the chamber and the water level at the upper level these relative values are given directly by the system (e.g. labeled with level difference). The operating mode indicates if the system runs in automatic mode (start is initialized by the operator and the sub-operations are run automatically) or in manual-remote mode (each sub-operation has to be initialized by the operator manually). For some locks different locking categories, depending on the size of the ships or amount of ships that need to be locked, are furthermore differentiated.

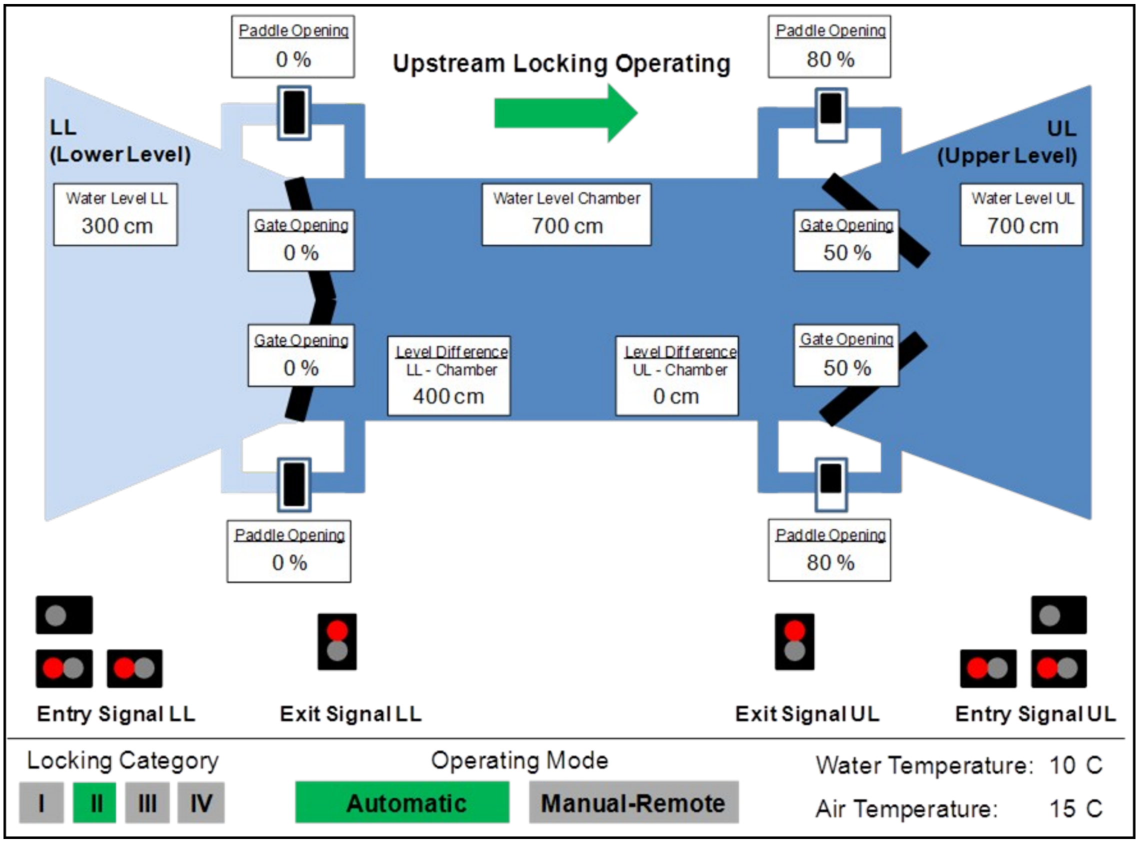


Figure 4: Example depiction of the GUI of the control monitor

CONCLUSION AND OUTLOOK

In this paper a concept for the ergonomic design and work organization in RLOCs is introduced. An approach consisting of two parts was used. The current state of 14 RLOCs in Germany was investigated regarding work process, physical and environmental ergonomics and ergonomics of the human-system interaction. Based on the results of the evaluation, recommendations for improvement were given and a new concept for the ergonomic design and work organization in RLOCs was developed. This concept includes an ergonomic concept for remote control and monitoring, an accordingly designed control panel and guidance for personnel management and scheduling. It differentiates four cases depending on the traffic volume. For each case a specific allocation of system(s) to operator is proposed and the respective ergonomic realization of the control panel. The decision on the case to be applied is based on the calculation via the guide for personnel management and scheduling.

The next step is to implement this concept to RLOCs and to investigate it in a long-term study. Therefore, a prototype control panel was constructed and is currently being discussed with the operators to validate the theoretical derived concept in praxis.

ACKNOWLEDGEMENTS

The paper refers to a project that was conducted on behalf of the Federal Ministry of Transport, Building and Urban Development (BMVBS) and the Waterways and Shipping Administration of the Federal Government (WSV). We are grateful for the close cooperation with the WSV and BMVBS and thank all participants for their contribution, especially the operators in the RLOCs for their support (contact: BMVBS, Referat WS11, Thomas Rosenstein).

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