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Ergonomic Design of Mobil Interaction Devices to Assist Field Worker and Increase Process Safety

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Industrial development in the age of digitalization requires the implementation of smart devices in order to aggregate data for process optimization. In modern organisations, the field operator uses smart devices (display screen equipment): not only for communication, but also for data acquisition, handling and in some cases, switching operations. The new devices have to fulfil several requirements: facilitate the data processing, assist the operator's interaction, benefit the operational procedure, and increase the system safety. To meet these requirements, the development of digital interfaces should be more than transferring paperwork into data sets without navigation units. New interaction systems should be chosen according to the task to be performed and designed in a way to suit the safety system, technical organisation system, and task management in particular. There are several general design rules for display screen equipment, but an appropriate change management is equally important for being able to select useful devices and to implement new technologies successfully. This comprises, for one thing, an analysis of the technical network and computer system; but should also include a task analysis. To increase the operator's acceptance by detecting their needs and preferences, the participation of the operators in the procurement process is required. In order to develop the special design and organisational implementation of new technology, a specially generated checklist can help practitioners to examine the basic network, hardware and software. The use of this list in an appropriate example will demonstrate the optimisation process of the operator's workflow and his safety behaviour using modern mobile devices.

1. Introduction

Many industrial control operations are carried out with visual display screen equipment from control stations. In order to optimize the efficiency and the safety of the work process and production process, the analysis requires data regarding the plant status and several system conditions (Murchison 2019). In addition to operators in control centres and control stations, the field worker gathers data during his work process to control, maintain and optimize the plant system and the production process (Jones 2019). Documenting his work steps in the past, the field worker used paper formulas to document the process data and safety measures. In the age of digitalization, a substitution of paper for mobile devices is taking place at an increasing rate (Lee et al. 2016). These devices are notebooks, tablets, and smartphones. The mobile devices ought to

- record and transmit data and information in an efficient and safe way without transmission errors,
- support the field worker in his workflow on a regular and useful basis,
- realise and assist the cooperation or collaboration with control centres or control stations,
- provide background information about the service object and environmental circumstances, and
- provide help in emergency situations (Lapierre 2016).

To meet these demands, the devices should be task adequate selected and designed in accordance with the work environment (Lafrenz 2018). In the case of changing work circumstances, the field workers should be able to adapt these units to their modified demands. Additionally, the workers should be able to adjust and remove default settings according to their individual needs. At same time the cyber security of the network between mobile devices and control stations must be ensured independently from any ergonomic settings. There

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are requirements and measurements to protect the information system in the recommendations of the German Committee on Work Equipment (ABS 2019).

1.1 General Requirements

The mobile devices most commonly used by employees for their work are display screen equipment according to the German Workplaces Ordinance ("Arbeitsstättenverordnung", ArbStättV). Table 1 lists the main requirements of this ordinance concerning mobile devices.

Table 1: Requirement concerning mobile devices as portable display screen equipment for mobile use

Requirement	Purport	Measure
Size, shape and weight must be task appropriate.	Avoid physical and mental strain by matching the size, shape and weight of the equipment	Select equipment with a bigger screen and therefore higher weight like notebooks and great tablets for tasks with equipment that uses storage surfaces or attaching systems. Select equipment with a smaller screen, a shape appropriate for wear on the body and a low weight for high motion tasks, which only require a simple graphical user interface.
Use screens with low reflecting surfaces and use in such a way that screens are free of interfering reflections and glare.	Avoid strong eye strain, the disturbance of user interactions and user errors.	Use antiglare screens, protective film and places with sun protection.
Only use for a short period or special tasks which cannot be carried out with any other display screen equipment.	Avoid using portable devices and therefore more strain if the task can better be completed at workstation with superior ergonomic conditions.	Manage work and user interactions so as to carry out extended tasks at workstations with optimal ergonomic work conditions.
Only use equipment with alternative means of input in accordance with the tasks and with the objective of optimum relief for workers.	Main input means are mouse and keyboard. These should not be replaced at all, but can be complemented with input devices like touch screens, voice input etc., if this can optimize the strain of the workers	For example, do not use touch screens for the input of long text passages
Using of portable equipment stationary at workstations, all the requirements of stationary display screen equipment must be implemented	To optimize workers' strain, portable equipment must not substitute stationary equipment. Portable equipment with a separate ergonomic keyboard and ergonomic screen is allowed.	Connect mobile devices with a keyboard and screen e. g. by docking station or Bluetooth
Provide task appropriate software	Implement software which provides the workers with the optimum support	Analyse the tasks and workflow of the workers, identify the demands and implement a new software package on a systematic basis

1.2 Safety and Design

Mobile devices are work equipment according to the German Ordinance on Industrial Safety and Health (Betriebssicherheitsverordnung – BetrSichV, German implementation of the directive 209/104/EG). The employer must ensure that the employees are provided with work equipment which is suitable for the conditions given at their workplace and which guarantees the safety and health of employees. In the selection and use of work equipment, the ergonomic aspects of the workplace, work equipment, work organization, work sequence and task shall be taken into account.

Error prone interactions and communications can be related to critical incidents caused by poor decisions and user errors (Lafrenz et al. 2011). By sending pictures, current information, additional warnings and alternative action processes, well designed mobile devices support the communication of field workers and operators in control centres in order to avoid misunderstandings and wrong decisions. The navigation and local detection of devices can help external service workers to orient themselves in the field and avoid errors due to the selection of the incorrect maintenance objects and locations.

2. Findings to Optimize the Implementation of Mobile Devices for Field Operators

2.1 Field Studies to Examine Mobile Devices' Impact on Communication Process, Tasks and Workload

To examine the impact of mobile device usage on the communication process, tasks and workload of control room operators and field workers, a field study as well as in depth interviews were conducted in 2018.
Three companies operating in the energy supply, power generation and security sectors took part in the field study. All field workers used sector-specific software, either on smartphones or tablet/notebook devices, while in the control rooms complementing communication software was used on stationary computers. The mobile devices were used for maintenance and cleaning, planning and surveillance tasks. The new software mainly offered a digitalization of formerly paper-based tasks.
The data acquisition, amongst others, focused on changes in the communication, tasks, work interruptions, the number of unclear situations and information when using the mobile devices compared to previous paper-based work. The field research included silent and participatory observations with questionnaires and interviews. The silent observations were task adequately structured in accordance with a prior taxonomy of ICT depending on the operating status and executed with a checklist of potential stress factors and indicators for assistance degree. In the participatory observations the task data was collected via questions for the field operators during his work with afore mentioned mobile devices. Results were finalized with interviews after the operators' work. The data of observations, questionnaires and interviews comprised the communication and information flow, efficiency of the communication, communication errors, improvement suggestions, four-eyes principle, work break in accordance to communication, unproductive delays, unclear situations, and amount of information. In order to capture the strain and the acceptance of the field operators, the standardized questionnaires NASA-TLX (Hart 2006) and TAM3 (Venkatesh und Bala 2008) were used. The perceived usability of the ICT was collected according to Isonorm-S (Pataki et al. 2006).

2.2 Results of Research: Requirements of Networks System and Selection of Adequate Device

With regard to the above-mentioned factors, no major changes in communication processes, tasks or workload due to mobile device usage were observed.
Using the new equipment and respective software, all participants experienced the highest strain during task processing, in mental (*Median* = 53, *Range* = 21 - 85) and physical demand (*Median* = 46, *Range* = 32 - 63) as assessed with NASA-TLX percentage scaling. Noticeably low was the perceived frustration (*Median* = 7, *Range* = 2 - 58).
Acceptance ratings of control room operators were overall positive, with highest values for the dimensions 'perceived usefulness', 'perceived control', 'perceived joy', 'subjective norms', and the 'relevance for work/task performance' with medians ranging from 5.25 to 7.00 (assessment on 7-point Likert scale of TAM). Field workers rated the 'relevance for work/task performance' and the 'quality of results' the highest with *Median* = 5.00, *Range* = 4.67 – 6.00, and *Median* = 5.00, *Range* = 3.00 – 6.00, respectively.
Given the heterogeneity of used equipment, the usability ratings were quite similar for control room operators and field workers, with highest ratings for 'controllability' and 'conformity with expectations'. The former dimension received a median rating of 5.20 (*Range* = 4.80 -6.40 for control room operators; *Range* = 4.20 -6.40 for field workers), and the latter dimension a median of 5.60 (*Range* = 3.20 -6.60) for control room operators, and 5.20 (*Range* = 4.00 -6.80) for field workers on the 7-point Likert scale of Isonorm-S. A detailed results report can be obtained from Oehme et al. (2019).
Using the new equipment and respective software, all participants rated the communication as more efficient or the same as before. The communication was still considered to be only marginally affected by errors. On the whole, the merging of several systems into one, the online processing of the data and the digitalization of the used documents and protocols were seen as the reasons for a more efficient and error-free communication. In the observations, all the required information was available in the control rooms and in the field. The participants stated that they were provided with the relevant information using the new mobile technology, and in some cases better than before. The participants were provided with more information using the new software, e.g. in the form of protocols of currently unvisited facilities. However, since it was the field workers' choice to use this information, they did not experience an information overload.
Despite the observed acceptance of the participants regarding the usage of software and hardware for mobile application, the investigation showed that the systems and devices used had some shortcomings. These included missing functions that made it necessary for field staff to carry additional paper-based documents or task-inadequate hardware choices (e.g. reflective screens for fieldwork). The participants emphasized the importance of easy handling and the possibilities for individualizing the devices. These statements were supported by the finding that the systems that were rated best in terms of usability and acceptance were those which were specially adapted to the needs of the users.

The greatest difficulty that became apparent while using the new mobile technology was the lack of mobile network coverage at some locations. This prevented access to an online system and disrupted the workflow. It also hampered the field investigations, making it difficult to coordinate the scientists' observations on site in the field with the colleagues in the control room.

2.3 Implementation of new Devices: Planning and Change Management

To complement the field study, four in-depth interviews were conducted: with a network distributor, two energy and water suppliers, and a transport company, who were planning to introduce mobile devices, i.e. smartphones and tablet computers in their fieldwork. The digitalized tasks envisaged included automatically calculated step-lists for switching operations, the comprehensive retrieval of information from the plants, staff planning, and reporting and documentation (e.g. of malfunctions). In contrast to the field study, three of the interviewed control room companies aimed for a collaboration between the control room operators and field staff during the completion of the task.

The interview participants were asked about their anticipated challenges when introducing new information and communication technologies (ICT) in the near future. The participants' primary demands were also anticipated as the greatest challenges for control rooms: firstly, and foremostly, a functioning infrastructure, including the connection of the ICT to the control system, the matching of hardware and software, and the possibility for the online use of the system. These factors require a good mobile network coverage or WLAN in the systems. The interviewees also planned regular updates of the systems used. For this purpose, it would be necessary to create customized solutions which remain adaptable to the changing requirements rather than using off-the-shelf products.

The interviewees anticipated problems after the introduction due to a lack of acceptance among older employees or employees with little technical affinity. In addition, problems might arise due to the lack of a market for new, mobile ICT in Germany. The participants perceived a low number of system manufacturers, complicated licensing models and a lack of contacts.

Overall, the requirements for the new systems seemed to be driven by a user-centered process and the plan to start with a soft introduction of the systems with voluntary use. A soft introduction means that initially, only a few selected colleagues are equipped with the new devices and additional employees join in later. A company can also start with a very basic version of the new ICT and subsequently implement additional processes and functions. These are important aspects of change management. Successful change processes in companies are always linked to good change management. Change management can be defined as the control of comprehensive, planned changes in companies (Kohnke, 2005). It is primarily focused on the people in an organization, the interdisciplinary aspect of change (see Kohnke, 2005, Stolzenberg & Heberle, 2009, Chies, 2016).

2.4 Checklist of Network, Hardware and Software for Successful Implementation of Mobile Devices

Based on the findings of the field study and in-depth interviews as well as a comprehensive literature review, a checklist for introducing a new mobile ICT for communication, information exchange, and planning tasks was derived. It touches on six topics that are both organization- and development-related: Basic Requirements, Organization, Hardware Control Room, Hardware Fieldwork, Software Development, and Work Organization. The topics, which have to be addressed by the control room company, mainly focus on the basic requirements, organization and work organization as well as the hardware for control room and fieldwork. In particular, the Organization and Work Organization topics deal with the interaction between the control room company and the selected system manufacturer. The software development is the responsibility of the system manufacturer/developer, but the steps of the development should take place in an interactive process. The central issues here are the user-centered development, i.e. the inclusion of the employees and involved departments in the development process. These also consist of the transfer of user requirements to the new ICT and usability testing. The checklist provides 183 checklist items, which are supplemented with 66 practical tips and examples for better comprehensibility. Each item can be checked and comments can be added. Figure 1 provides an overview on the checklist content (for detailed overview refer to Oehme et al., 2019).

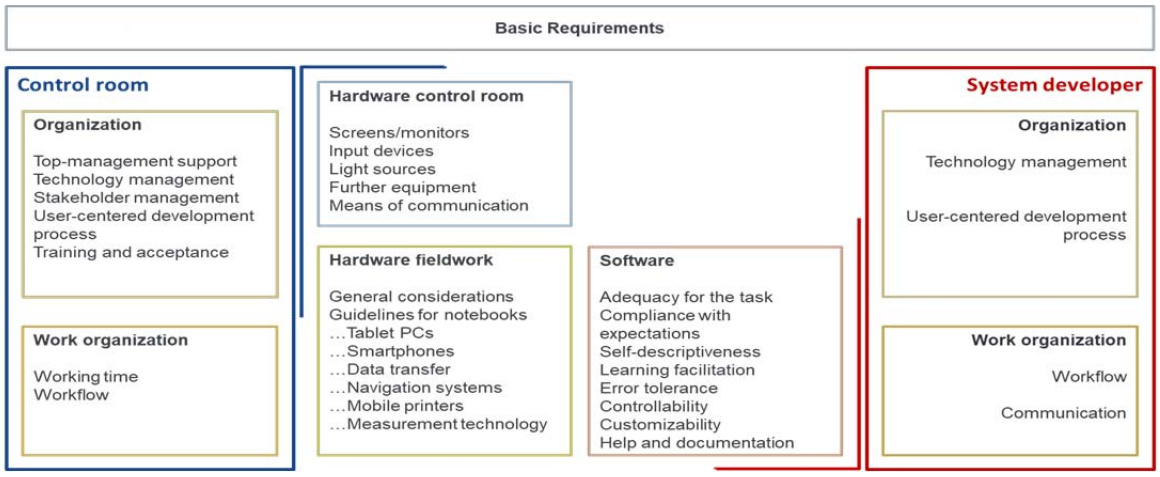

Figure 1. Check list topics and high-level content

Basic Requirements checks concern the basic organizational requirements for the introduction of new mobile ICT in control rooms. They should be considered or checked before the actual project starts. A mobile or WLAN network with stable availability is mandatory at all work locations, either by excellent network coverage or by retrofit WLAN set up. The planned changes should be controlled throughout the project as part of the change management. Within the scope of the stakeholder management, future users should be involved in the project. For this purpose, the procedures and methods of a user-centered development process have to be applied. If the new system is to be integrated into existing systems, the new system should be compatible with them. The use of as few different systems as possible should be considered.
Checks related to the **Organization** are mainly implementation recommendations and include aspects to facilitate top management, technology- and stakeholder management. Furthermore, recommendations for a user-centered development process and the suggestions for training measures are essential to ensure safe and appropriate use, user satisfaction when using the systems and resulting acceptance.
Hardware Control Room checks are subject to requirements regarding health and safety regulations. The implementation of recommendations for screen hardware and other features at the workplace intends to ensure that these regulations are complied with. The recommendations for this topic concern control room ICT equipment. They should be considered during the requirements analysis and when procuring new technologies. Correspondingly, **Hardware Fieldwork** is also subject to the requirements of the health and safety regulations. The suggestions on general aspects for implementation in the checklist are followed by device-specific recommendations. The checks focus on the requirements for the ICT of the field staff. Again, these should be considered during the requirements analysis and when procuring new technologies.
Software Development checks focus on software quality measures. The quality of a software package can be determined by usability testing. Usability is related to system properties such as task adequacy, self-descriptiveness, controllability, expectation conformity, error tolerance, individualization and learning facilitation (DIN EN ISO 9241-110), and by further recommendations. The checks regarding the usability of the software should be considered during the software development.
In the **Work Organization**, the allocation of the overall task in the work system to the available resources (man and machine) is determined. In this context, various stress factors play a role: the working time, workflow, and communication. These aspects are divided into the internal work organization and the work organization in cooperation with the manufacturer. The checks under this topic should be considered when organizing the field work.

3. Conclusions

Mobile ICT should assist the field workers for several tasks and for cooperation with operators in control centres. To optimize the operators' workload and increase the system safety, mobile ICT should be selected on a task-adequate basis and ergonomically designed. There are several requirements for the use of mobile devices at work, e.g. according to the German Workplaces Ordinance: New technologies should not substitute stationary equipment but complement the technical system to optimize work conditions. To ensure the system safety, error prone interactions should be avoided. New technologies should therefore be designed in accordance with the work environment and the special demands of the field workers. The study of control rooms in

Germany revealed that modern, mobile ICT is not very widespread in current use. If available, smartphones, tablet PCs and notebooks are mainly used in the field. While the purchased hardware is not always suitable for mobile outdoor use, the new software offers a digitalization of formerly paper-based tasks. Therefore, so far, the tasks and work processes have changed very little. These findings, however, were established from a very limited sample, so more comprehensive ICT systems might already exist in other control room facilities. The systems currently being planned for use will also extend the previous range of functions. This will presumably result in additional requirements for the hardware and software. In the course of collaborative work and a more comprehensive scope of functions of modern ICT, which entails a more intensive exchange of digital information between the locally distributed employees, observations that are more detailed could be carried out in the future. The checklist for the introduction of modern, mobile ICT derived in the project provides a guideline for designing new processes in such a way that the choice of hardware is more strongly oriented to the context of use and the software is adapted to the needs and requirements of the control room operators and field staff. It is recommended that experts in human-technology interaction or usability accompany the process. The checklist can also be used to assess and optimize the existing implementation of new ICT, albeit not covering aspects of cyber security and general system safety. Unsurprisingly, the basic prerequisite for the wide-ranging use of modern, mobile ICT remains a stable, nationwide mobile communications network.

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