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Modern ICT to Support the Operator Controlling Complex Systems

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Many process control and service operations in productions are carried out in control centers via visual display unit workstations. The operator's tasks often have great relevance for system safety.
Modern Information and Communication Technologies (ICT) should support the operator's workflow and their supervisory role. Multimodal output devices with task adequate structures of relevant information, process variables and units intent to improve the situation awareness of the operating staff. Intuitively designed input devices should promote quick responses in time critical situations to prevent loss of control. Mobil Display Screen Equipment can help to improve the communication between operators in control centers and plant operators in the field.
In order to support operators optimally, modern ICT should be selected, designed and implemented carefully in the operating concept. Additional it should be adaptable to the operator's needs in a wide variety of situations.
Possible risks, requirements and measurements are described using examples of operation errors and better masteries of situations as improvements due to new ICT.
Within Risk Assessments of the control system the requirements of ICT are determined to optimize the operators' workplace and workload in order to support the operators' safety behaviour for their own and other employees' occupational safety and health.

1. Introduction

Many process control and service operations are carried out in control centres by operators. Besides their central tasks of coordination, regulation ,process control and others, like traffic and safety services, the central control centres often serve as a contact point for visitors, contractors and other people. Due to this variety of tasks the job of an operator can be very complex and bear a lot of responsibility. Especially in high risk and reliability industries the operators' work plays a key role for the process safety system (Bockelmann et al., 2012).
The majority of tasks in control centres are carried out via visual display unit workstations using screen equipment (Jeschke and Lafrenz, 2012). All newly applied work systems are technological evolutions inspired by work centralisation and process digitalisation. Accordingly new ICT like touchscreens and gesture control are discussed as a possible addition to conventional displays of personal computers with a keyboard and a mouse in order to structure, prioritise and distribute data and information.
Structured interviews with 39 participants working in different areas were conducted to analyse the current and prospective use of modern ICT in control centres (Lafrenz and Jeschke, 2017). The interviews were analysed and the following questions arose from the results:

- What kind of modern ICT are already implemented in control centers or being considered for future implementation?
- Why and how are the new systems selected and implemented in the operating concept of the control centres?
- For what kind of tasks in control centres are new ICT useful?

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- Which experiences resulted from the implementation and use of new ICT?
- Which insights for future application of new ICT can be gained?

The participant's specified reasons to introduce new ICT systems. The most prominent reasons to introduce new ICT into the workplace are the intention to reorganize or modernize the work environment, however accidents or the aim to increase efficiency can be a reasons to reconsider the current operating concept. Furthermore the participants listed an increase in efficiency, reduction of mistakes and the better mastery of the situations as improvements due to new ICT (see Fig. 1).

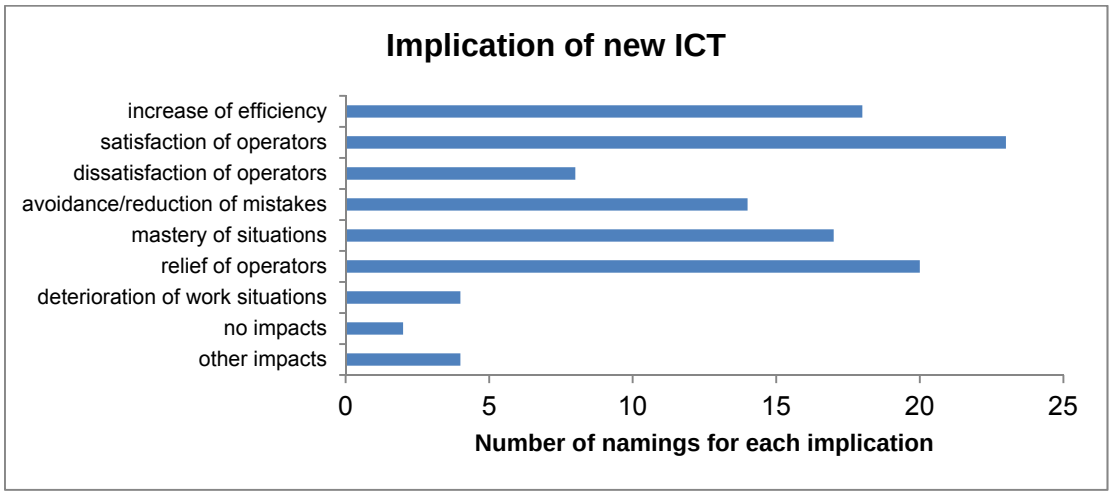

Figure 1: Named implication after implementation of new ICT in control centers

Two important preconditions for successful implementation of new ICT and thereby improvement of working conditions are the participation of employees during the procurement process and a structured change management, in order to increase acceptance and shorten the familiarization period with new ICT.

1.1 Challenges of introducing modern ICT in process control operations

In order to support the operators in their work, increase situation awareness and avoid operating errors, a control concept with new ICT should be developed on the basis of a task analysis between the systematic processes of transformation (Bockelmann et al., 2012). Analysis methods for Human Factors (Root Cause Analysis) determine e. g. improvements of reliability of the individual work execution by operating staff (Nakagawa and Shibata, 2016). Therefore results of Root Course Analysis can give helpful references to what kind of support is needed in a specific situation, interlocks as well as data and information management (Lafrenz, 2018). The ISO Series of Standard 9241 ff., Bockelmann et al. 2012 and ASM Consortium Guidelines describe general requirements and solutions for effective operator display design concerning content, style, layout and navigation of displays. Creating a task-appropriate user interface for the operators' demands the inclusion of options like flexible display arrangement and individual settings. They have shown to be especially useful to the user (Nickel and Nachreiner, 2005). Furthermore, the following actions have proven to positively influence the acceptance of new ICT (Lafrenz and Jeschke, 2017):

- Presentation of best practice solutions of ICT
- Test installation with new ICT parallel to existing control concept
- Special training

A statistical analysis of the interview revealed significant association between change management (including participation and extensive training) and satisfaction, situation awareness or avoiding mistakes of the operators as an impact of new ICT.

After the structured interview a delphi workshop was held, in order to discuss the future of ICT in control centers (Lafrenz and Jeschke, 2017). One result was: The change management, especially the participation of operators, should adapt to the safety culture and responsibilities of the organization. The participants of the workshop confirmed the idea that difficulties encountered during the launch of new ICT like different technical affinity of operators are controllable and don't reduce positive effects of new ergonomic task-oriented ICT.

Additional usage of special ICT targeting fault diagnostics, presentations of group discussions, training for major hazards (Lapierre et al., 2016) and planning of emergency procedures should be recognized.

2. Concepts and Questions of the Task-Oriented Selection and Use of ICT

The ISO Series of Standard 9241 ff., requires the human-centred design for human-system interactions with the goal to improve usability, safety, health and well-being of humans in the system. These aspects include the avoidance of harm from use e. g. due to negative impacts during interactions with process control systems or failing to adequately complete a task. Important dialog requirements concerning task suitability include:

- Suitable information
- Suitable interactions
- Suitability for exploration
- Suitability for learning

This includes the choice of which information is shown to the operator and which are for each step of the process, thereby excluding irrelevant or rarely needed information. This factor must match in order enable the operator to make well-informed decisions (Tognazzini, 2014).
With regard to the selection of useful new ICT: 3D Video Applications aren't used to overview a plan of a plant system, because 3D visualization doesn't give more relevant information than 2D. 3D visualization can be helpful to plan inspections in difficult and dangerous areas (Lafrenz and Jeschke, 2017).
There are several aspects for occupational safety and health with regard to an adequate design of control centers especially concerning the design of ICT and operator interfaces:

- Optimization of mental workload to avoid negative strain consequences
- Ergonomic design to avoid negative strain consequences due to physical stress
- Prevent hazards of installations outside the process control room optimizing the works condition of operators in the control room, preventing inaccuracy, misinterpretations and mistakes

The central question to select, design and use new ICT is: How can new ICT help to prevent hazards and negative strain consequences without causing to new problems?
Answers should be gained through risk assessment which includes e. g. process safety analysis, task analysis and an evaluation of the current change management.
All known requirements for Process Control Technology (PCT), workplaces in control centers with conventional visual display units and design of the human-machine-interfaces are relevant for new ICT. In many cases the new technology will be implemented additionally to pre-existent ICT (Lafrenz, 2018). In these cases the new technology should comply with the standardized rules of the current safety and control concept (ASM, 2008). The risk assessment of the workplace, the control tasks as well as the plant safety help to determine the reliability and ergonomics of the new ICT design (Schwarz et al., 2010 and Hurlen et al., 2012).
The risk assessment should include the aspect, that more ICT equipment increases the space requirement and the temperature control via air condition in the control center.

2.1 Examples of operation errors and better coping strategies as improvements due to new ICT

One example for dangerous work and important communication is maintenance work in the process industry. In the process industry maintenance is frequently carried out while the plant is still in operation and has to be carefully planned in order to protect staff from hazards. Such hazards are for example dismantled safety devices or opened installations of the running plant. Cooperation between operators and maintenance staff is therefore essential for occupational safety and health, and bad communication can cause serious and even fatal accidents as the following examples show:

- One maintenance worker died while repairing a stirrer in a reactor, because an operator switched on the stirrer.
- Several employees were injured when an external maintenance worker opened a compressor under pressure.
- A maintenance worker was burnt by a hot substance while cutting a tube.

Inactions between mobile devices of maintenance staff and visualization units in control centers can display the location of the maintenance workers. Additional control operators can send messages to the mobile devices of the maintenance workers and other field operators as well as get pictures and video captures of the location and the maintenance asset (Wille et al., 2012). Identification systems using barcode reader on mobile devices can help to avoid incidents caused by confusions of maintenance assets.
Modern control systems help planning and coordination of maintenance work using visualization of necessary steps for safety of maintenance process. New technologies like virtual reality can help to train maintenance works and to prepare on-side inspections of hazardous areas.

2.2 General Requirements in ICT supporting operator's tasks

General principles of interactions like self-descriptiveness, user control, and ease of learning a new technology apply to new ICT. According to ISO 9241-110 the purpose of new ICT is to increase task performance and user experience.
These aspects should be determined through systematic analysis (Lafrenz, 2017).
For example one measurement of physical input devices (IP) is the movement time to a target (MT) in relation to the index of difficulty (ID) depending on distance of move (D) and width of the target (W) (ISO 9241-410):

$$IP = \frac{MT}{ID} = \frac{MT}{log_2 \frac{D+W}{W}} \quad (1)$$

Cockburn and Brewster (2005) measured values of IP = 6.17 bits/s for using a conventional mouse and for using mouse with force feedback 6.04 bits/s.
The participants of the interview and of the Delphi workshop predicted, that new physical input devices like joysticks and touchscreens won't replace keyboards or mice in control centers, but could be added for ergonomic reasons (joystick, to reduce stress on hand and wrist) or special tasks (touchscreen, to quick point) (Lafrenz, 2017). Another area of application for new ICT is visualization of the real time process status and the support of operators' decisions (Aas and Skramstadlive, 2010). One example for visual support is a collaborative platform, which shows the operators working in- and outside the control room the current status and responsibilities of several staff members on the floor (see Fig. 2, Lafrenz, 2018).

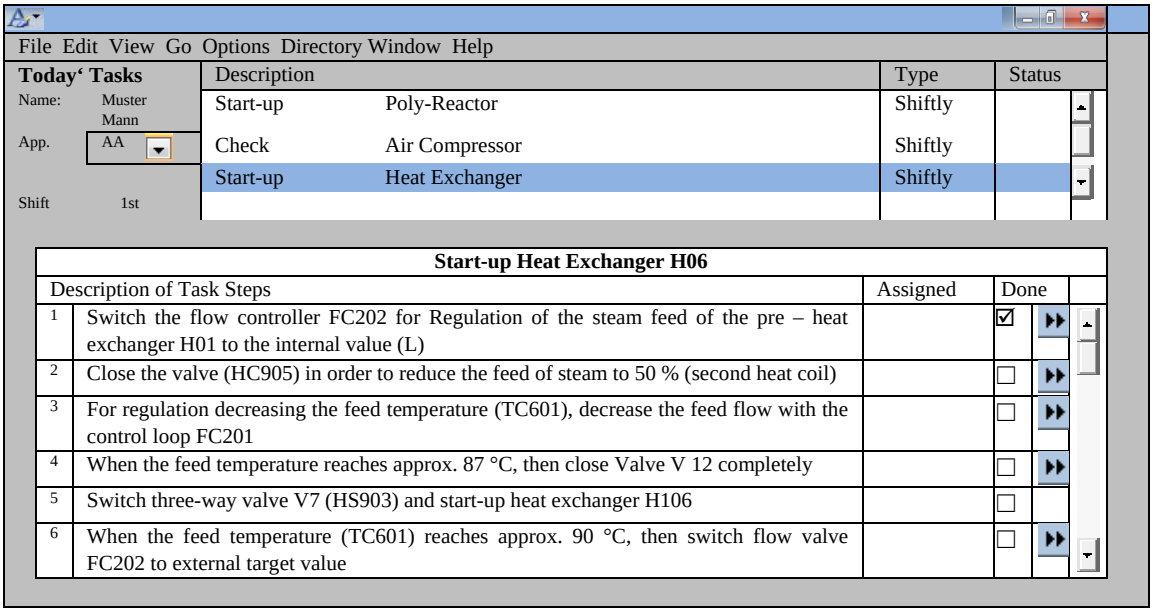

Figure 2: Example for a collaborative application user interface (according to ASM, 2010)

The displayed information and data should be structured and grouped. There are established rules on how to display important information on a screen, for example ISO 9241-112. In contrast new technologies are more flexible thanks to using multimedia procedures and the option to choose between a variety of printed hardcopies, online or mobile electronic procedures. What kind of media should be provided depends on the context or intention of use (ASM, 2010). For reading long text passages printed hardcopies or large e-ink devices can be the preferred media (Tegtmeier et al., 2016). With new functions like taking and transmitting photos and movies as well as identifying the equipment in field, modern digital devices become more comfortable than paper procedures (Lee et al., 2016).

3. Methods and Research to find out the optimal Design of Control Centres with ICT

Based on the structure interviews described in Chapter 1 laboratory and field studies were conducted in order to determine the optimal design of video visualization (Ries et al., 2018). In the laboratory study the mental workload and the perceived usability of using different kinds of media for surveillance with video cameras was rated by control room operators:

- Autocycling images
- 3D visualisations
- Distorted and mirror images
- Augmented Reality

Field studies investigated the mental workload of control room operators and field operators using modern ICT in the control room or mobile devices like PDA in the field in order to support their communication (Lafrenz, 2017). In parallel studies the results of a Root Cause Analysis as well as the insights gained from analyzing the collaborative work between control operators and maintenance teams in the field were used to identify possibilities to improve the communication between all employees and prevent human errors caused by misunderstandings (Lafrenz, 2017). The sections list of a Root Cause analysis in order to structure the reasons of failure can help to determine an operator's visual display design and content:

1. Technical disturbances and failures
2. Asset management
3. Taxonomy and Information management
4. Collaborative Platform
5. Instructions and other work documents
6. Deposit responsibilities
7. Resource management
8. Possibilities to make comments, give tips and improvements
9. Support task and control steps
10. Rules of violations

All results should be entered into a risk assessment tool to design control centers suited for the implementation of modern ICT in the operators' visualization platform and mobile devices.
New technologies are commonly added to the established control system. In order to ensure an optimal supplementation of the current system, requirements and solutions for transformation and introduction of the new system are given. The assessment focuses on:

- Personal and task requirements, multitasking
- Spatial design of control room
- Ergonomic design of work places: furniture, displays, lighting
- Human-Machine-Interaction
- Work environment
- Work organisation

Between these sections indicators of ergonomic design will be enquired and the degree of performances will be documented (one example see Tab. 1).

Table 1: Example of Requirements to spatial equipment of control rooms

Sector/Indicator	Requirements/Metrics		Sources information	Degree of performance	measure
viewing distances monitor at workplace	According to monitor size	Min. 50 cm Opt. 70 cm	ISO 9241-5	☐ high ☐ medium ☐ low	

In many real life situations taking all requirements equally into account in order to optimize a workplace isn't practicable. In these situations solutions to compensate stress and promote well-being should be assessed and prioritized. This can be accomplished in the following ways:

- Spatial and task-specific separation of different operating concepts and user interfaces
- Autonomy of employees in determination of breaks, task design and taking up support
- Individual change of settings of graphic user interfaces
- Work rotations and flexible tasks, but standard breaks after stressful situations
- Relocation of heat radiating components from the control room

4. Conclusions

Modern ICT provides a wide variety of possibilities to optimize an operator's work and workplace by granting them more flexibility and increased individualisation of operating concepts. Visualizations of the real time process status and structured dates on graphic user interfaces increase operators' situation awareness and support operators' decisions of process control.

The achieved level of optimization is dependent on the selection, design and implementation of the new technology.
The results of a Root Cause Analysis can help to find out possibilities to optimize operator's workload and to improve the process control using modern ICT.
Answers of how can new ICT help to prevent hazards and negative strain consequences without causing to new problems should be gained through risk assessment.

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