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Identify the Causes of Errors to Implement Accurate Improvements in High Automated Facilities of Process Industry - A Case Study

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The increasing degree of automation and complexity of process plants raises the requirements on operators in monitoring and controlling process flow. Unfortunately the fast developments of automations are often not accompanied by understanding and consideration of the operators' capabilities. Therefore the number of accidents particularly caused by wrong decisions of operators is increasing. A concrete example is given by the explosion at Texaco Milford Haven refinery. Key factors that emerged from the Health and Safety Executive's (HSE's) investigation are that the control room displays did not help the operators to understand what was happening and there were too many alarms and they were poorly prioritized (HSE, 1997). Common problems that had caused disasters are equipment failures or software faults, insufficient knowledge of the operator about the process and system design failure due to the ignorance or misunderstanding reaction to the displayed information (Kletz et al., 1995). While the safety analysis methods focus on the errors caused by the components, there are currently no methods that are focusing on finding possible causes of errors in the system that lead to operator's failure.

In previous researches by the author, a specific analysis method was developed. By means of the method, the relationship between alarms, their causes and consequences can be recognized, so that control systems and control rooms can be designed accordingly to better understand operators' requirements in performing remedial actions (Löwe et al., 2010). This new developed method includes a technique to identify the Performance Influencing Factors (PIFs). The PIFs evaluation allows us to quantify how significant a specific factor affects the operator's performance during their work. This paper shows the determination of PIFs global weight (for the process industry) on several facilities of a refinery in Germany. The quantification of PIFs enables the identification of sources of errors and the implementation of accurate improvements in the system.

1. Introduction

Increased demands on productivity, efficiency and safety of the processes have led to a comprehensive computerization and automation of process functions. This modernisation caused a significant shift of operators' works and requirements. Through the implementation of Distributed Control System (DCS) operators have more distance to the real processes which leads to a reduction of their process understanding. To increase productivity and reduce costs, fluctuation and reduction of staffs occurs, while the work load is growing (Knegtering et al., 2009). Despite its advantages, e.g. optimal operation and reliability of process plants, the implementation of DCS had brought other (much bigger) issues of process safety. Through the high flexibility of DCS, it was significantly easier to implement a higher number of alarms. For these reasons, nowadays alarm-floods, chattering alarms and nuisance alarms appear in many control rooms which cause new safety problems in the modern process industries. Andow and Fittler (2005) for example have reported that plants with 20-60 alarms per hour are not uncommon even during normal operation. According to Kurz (2008), more than 60 alarms per minute can occur during alarm

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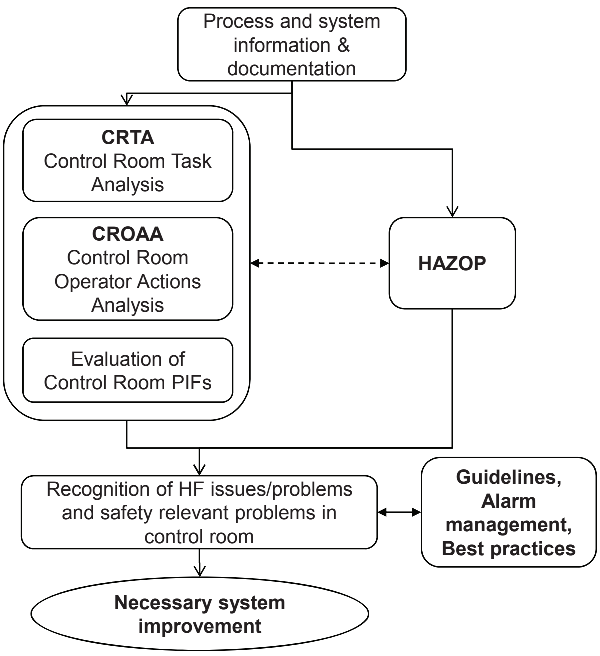
floods. In this situation, the operators must spend their concentration almost exclusively for handling alarms. Scope for proactive monitoring and management of the plant is thus no longer given.

With increasing requirements on the operators during the execution of their work, the optimal design of the DCS and the adequate design of alarm systems play a decisive role in terms of operator performance and therefore in process safety. To overcome various problems with control systems, assistance from different guidelines is actually available (Dunn et al., 2005, EEMUA, 1999, ISA, 2009). However, those guidelines for alarm design and management basically only provide recommendations to solve alarm problems without providing systematic approaches to reveal the underlying problems. Solutions recommended by the guidelines can only be selected properly and used if the exact sources of problems have been recognized. Hence, there is a need for a technique which provides a way to analyse what the system's deficiencies really are and what the operators are lacking, to be able to extract the most suitable solutions from guidelines. A method which is called Process Industry Tool for Operator Action Analysis in Control Room (PITOPA-CR) was developed by the author. The method provides a way to reveal operators' needs in performing supervisory tasks in control room, and to exploit this information in designing the DCS, configuring the control room and designing an alarm system based on best practices and guidelines.

2. Process Industry Tool for Operator Action Analysis in Control Room (PITOPA - CR)

PITOPA-CR allows systematic identification of possible errors during the implementation of supervisory tasks in control rooms. Through the analysis the relationships between "Alarm - Causes - Consequences" are depicted, and subsequently necessary system improvements can be derived. By means of the analysis, entire tasks of a process during normal operation and abnormal conditions are investigated. The goal of this method is the identification of necessary system improvements, so that the number of alarms during normal operation can be reduced and operators' errors during the abnormal operation or during the implementation of corrective actions can be avoided.

The method consists of three standalone analysis techniques that are associated with a HAZOP analysis: the Control Room Task Analysis (CRTA), the Control Room Operator Actions Analysis (CROAA) and a method to evaluate the performance-influencing factors (PIFs) in the control room. Figure 1 shows the basic structure of the developed analytical method PITOPA-CR (Löwe and Widiputri, 2011).



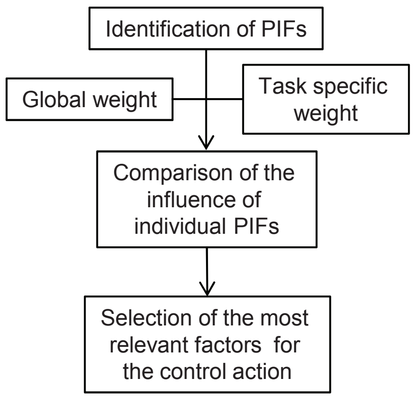


Figure 1: Basic Structure of PITOPA-CR

Figure 2: Procedure for PIFs Analysis

The results of PITOPA-CR enable the identification of system weaknesses in coping with human errors. Based on this finding, a way to optimize the design of DCS and alarm system configuration, which considered operators' capacities and limitations, can be provided. Moreover, the recognition of the most influencing factors in a specific working condition will give indications concerning the most necessary improvement in supporting the supervisory works in control room. The result demonstrates the most necessary improvements in supporting the supervisory works in control room, designing operator supporting systems, the human-machine interfaces or the overall control room configuration. This will lead to an optimization of DCS-Design on the whole to better apply to operator requirements.

3. Performance Influencing Factors (PIFs)

The procedure for the PIFs evaluation, during PITOPA CR analysis, is shown in Figure 2. The most important part of the analysis is therefore the identification of PIFs and their decomposition into sub-factors (also called attributes) and the determination of global and specific weights for each factor. In order to analyze a specific working condition, both the global weights as well as the task-specific weights must be determined. Based on the global and specific weights, comparison of the quantified factors against each other can be made. Global weights are assumed to be valid for any process plant. For an objective assessment of the plant conditions the task-specific evaluation should be carried out by experts using a guideline for each evaluation of a particular plant. This guideline was developed and validated in practical studies and depict a rating help for the assessor. This work will focus on how the PIFs and its attributes were identified, and how the global weights were determined through a survey on process industry plants

3.1 Identification of Performance Influencing Factors for Supervisory Tasks

In previous works a PIFs–catalogue was generated based on expert knowledge and practical experiences. Using this catalogue investigations were executed on several semi-automated plants in the chemical industry in Germany where the catalogue proved its practical usability. Nevertheless in this work a comprehensive literature research was conducted to guarantee the completeness of this catalogue. All of the identified PIFs have an influence on the situation awareness, workload and the vigilance level and consequently on the decision making process. The identification of PIFs and their attributes for supervisory works have to be established in line with the relevant concepts from cognitive and work psychology, e.g. situation awareness, mental workload and vigilance. The reason for the consideration of these concepts, in connection with the control room work, lies in its increased relevance due to the introduction of automation in the process industry. The importance of the concepts has been widely confirmed through investigators in different fields (e.g. aviation, medicine and aerospace), and in this work the relation to the control room environment was investigated.

As a result of literature searches in the areas of situational awareness (Endsley and Garland, 2000, Endsley et al., 2003), mental workload (Hancock and Meshkati, 1988, Gawron, 2008) and vigilance (Davies and Parasuraman, 1981), factors that affect the decision-making process in control room were identified. Those factors are grouped according to the respective group categories (e.g. man-machine interface, alarm system, etc.) and extend the existing PIFs analysis catalogue. The next step is the determination of global weights for the identified factors through an industrial survey.

3.2 Determination of the global weights – A Case Study

The global weights in the PIFs catalogue represent proportions of task-independent importance of respective factors for operator's performance. The sum of the importances is one. The weights were determined from the results of a survey using the AHP method. The AHP technique is a multi-attribute decision-making process and is used as a support to the particular case of decision options (with many not exactly quantifiable alternatives), to give quantified values for each option (Saaty, 1980)

The survey was conducted at a refinery in Germany at several high-automated facilities. As a survey instrument a questionnaire was developed and used. The questionnaires were distributed to different work shifts. Figure 3 contains a section of the questionnaire which consists of two parts. In the first part general questions about the work of the operators (e.g. work experience, general stress at work, consideration of human factors in the company and in the design of control room work, type of training and education) were asked. In the second part of the questionnaire, the operators should evaluate subjectively the importance of the respective PIFs. The result of the first part shows that about 70% of the operators have been working for more than 10 years. The stress level is considered as high to very high (particularly during abnormal conditions) by most interviewees. The most common stress factors are immediate environment, control room design, lack of qualifications (particularly to handle the abnormal conditions) and aspects of job design (lack of job rotation).

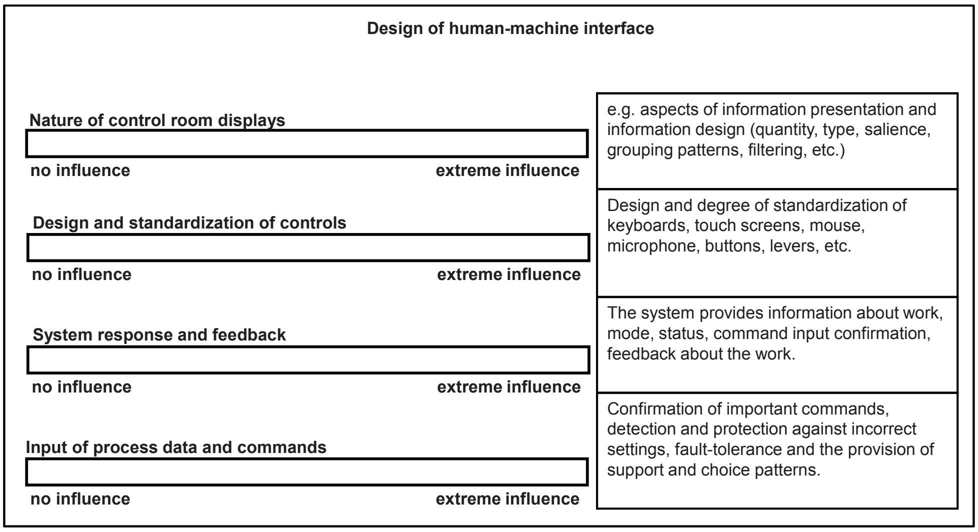


Figure 3: Section of the questionnaire

3.3 Results

Figure 4 shows all identified PIFs for the work in control room. In comparison to the list used in previous research works this compilation was extended by different parameters, e.g. the category Human-System-Interaction was completely added. The global weights for all recognized PIFs (50 factors) describing supervisory work in the process industry were evaluated with the help of Analytical Hierarchy Process (AHP) technique by Saaty (1980). For clarity reasons only the weights of the superior parameters are illustrated in Figure 5.

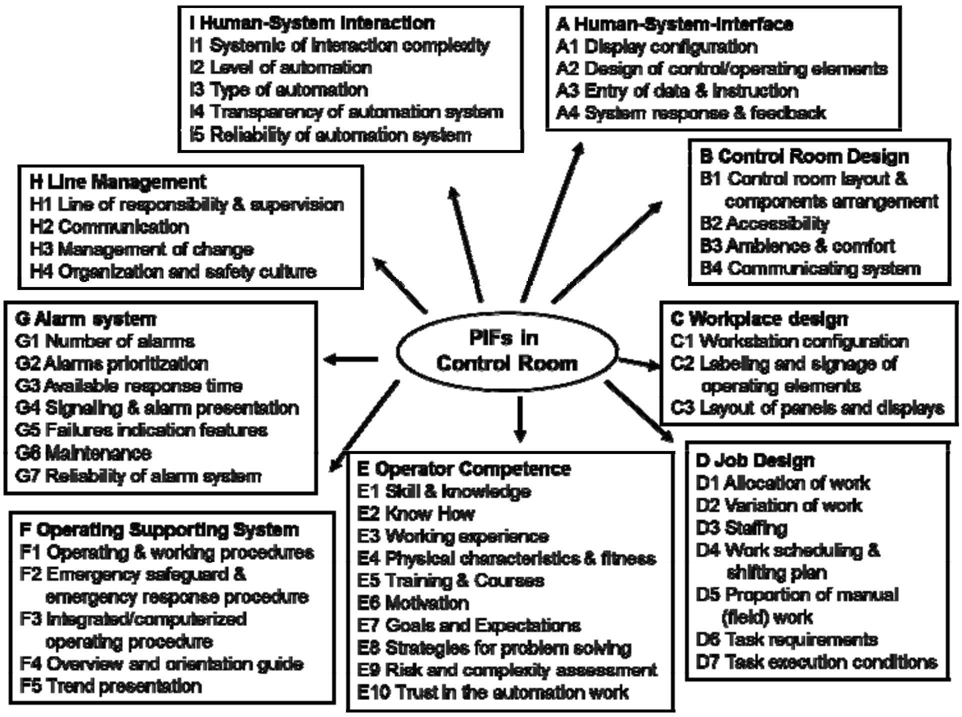


Figure 4: Identified PIFs for the work in control room

It can be seen that Operator Competence, Alarm System and Job Design are the most important factor blocks influencing the performance of the control room operator and should be given top priority in the design of control room operations.

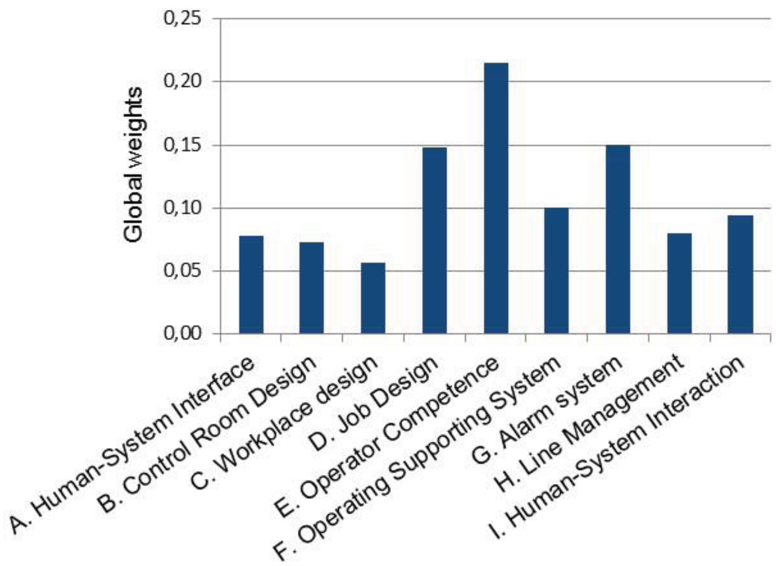


Figure 5: Results of the survey: Importance of different PIFs (operators opinion)

The importance of these factor blocks not only shows its global role for the general control room work, but also reflects the specific circumstances of the control room work at the refinery. A detailed analysis of the individual plant is done by quantifying the specific weights. The global weights should be independent of a specific plant and describe the importance of the individual PIFs. For that reason the new results are compared against the results of previous research studies in the chemical industry. For better comparability the factor block I. Human-System Interaction is cleared and the values for the global weights in the remaining 8 factor blocks are re-calculated such that their sum yields 1 again (Figure 6).

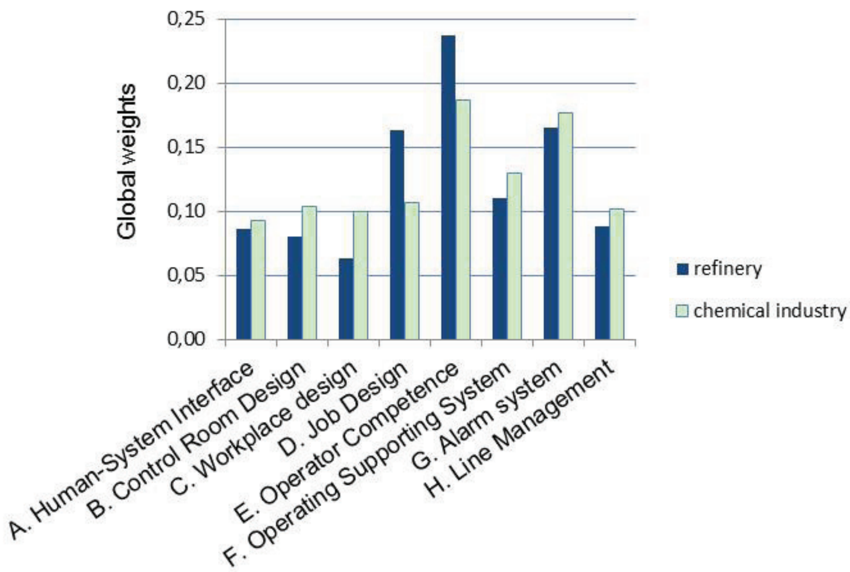


Figure 6: Comparison of two different studies: Global weights of PIFs

In this former study highest importance is allocated to Operator Competence, Alarm System and Operator Supporting System, followed by Job Design. The higher importance of Job Design in the new study can be traced back to the extension of this factor block by the attributes D6 and D7 (task requirements, task execution conditions), which received high rankings in the latest study. The previous study was conducted on semi-automated plants where the operators have to fulfill a substantial amount of work in the field while the operators of the full-automated processes in the refinery however usually do not leave the control room. Despite the diverging requirements on operators in the two studies the global weights of both studies show good agreement.

4. Conclusion

The analysis of the Performance Influencing Factors plays a key role in order to find the possible causes of errors that lead to operator failures, which is the prerequisite for systems improvements. In this work, using a decision making model for supervisory work and consideration of relevant concepts from cognitive and work psychology (e.g. situation awareness, mental workload and vigilance), all possible performance influencing factors were identified and added to the existing catalogue of PIFs from previous studies. Through a survey on several facilities of a refinery in Germany, using the AHP method, the global weights of PIFs were determined. The good agreement of the results of the new study against previous results demonstrates a general applicability and robustness of the developed method. Using the developed method with the PIFs catalogue containing the global weights in combination with the guideline for the rating, supervisory tasks in control room can be systematically analyzed and those factors which affect the operator performance most can be quantified. The recognition of the most influencing factors in a specific working condition indicates the most necessary improvements in supporting the supervisory works in control room, designing operator supporting systems, the human-machine interfaces or the overall control room configuration.

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