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Ergonomic Redesign of an Industrial Control Panel

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Abstract

Operator’s role in industrial control centers takes place in time, which is one of the most important determinants of whether an expected action is going to be successful or not. In certain situations, due to the complex nature of the work, the existing interfaces and already prepared procedures do not meet the dynamic requirements of operator’s cognitive demands, making the control tasks unnecessarily difficult. This study was conducted to identify ergonomic issues with a specific industrial control panel, and redesign its layout and elements to enhance its usability. Task and link analysis methodologies were implemented. All essential functions and supporting operations were identified at the required trivial levels. Next, the weight of any possible link between the elements of the panel was computed as a composite index of frequency and importance. Finally, all components were rearranged within a new layout, and a computerized mockup was generated. A total of 8 primary tasks was identified, including 4 system failure handling tasks, switching between manual and automated modes, and 3 types of routine vigilance and control tasks. These tasks were broken down into 28 functions and 145 supporting operations, accordingly. Higher link values were observed between hand rest position and 2 elements. Also, 6 other components showed robust linkages. In conclusion, computer modeling can reduce the likelihood of accidents and near misses in industrial control rooms by considering the operators’ misperception or mental burden and correcting poor design of the panels and inappropriate task allocation.

Keywords: Industry; Human engineering; Computer-aided design; Human factors and ergonomics; Man-machine systems

Introduction

Today’s advancement of technology and access to enhanced job interfaces, reduce working hours in hazardous industrial environments on one hand, and signify the human role in directing and managing such complex systems, on the other hand. Reports and documents suggest that inappropriate allocation of certain tasks to the human side might result in occupational near misses, accidents, or even disasters.

Control rooms can be considered complex socio-technical systems, representing significant levels of human-machine interactions. Operator’s role in control centers takes place in time, which is one of the most important determinants of whether an expected action is going to be successful or not. The required tasks in such contexts are defined as either receiving the information through various types of displays or monitoring and adjusting the operation process flow by means of designated controls. In certain situations, due to the complex nature of the work, the existing interfaces and already prepared procedures do not meet the dynamic requirements of operator’s cognition, making the control tasks unnecessarily difficult.

Developing efficient and consistent
human-machine systems is one of the focal points in ergonomics. Being applied to many different areas, such as industry, health care, traffic, etc, ergonomics aims to guarantee the participation of a multi-disciplinary team in all phases of the design process, so that task demands can be compatible with human capabilities, and unforeseen errors and subsequent incidents are moderated. Computer-based technology has been employed in ergonomic assessment and design of various industrial control-display interfaces. A typical design project of an industrial control room could be approached via two different methodologies: First, in regard to workstations' physical features and environmental parameters of the actual room, and second, in control-display arrangements and layout of the panels. International standard ISO 11064 defines an ergonomic design process for control centers and specifies analyses and verifications to be considered in each design phase. This standard consists of seven parts that has been applied in various academic and industrial projects. Part four (ISO 11064-4, 2004) of the standard contains a workstation design procedure and related physical requirements. Part five (ISO 11064-5, 2008) provides a checklist to verify implementation of design principles, a process description for display and control specification and high level alarm recommendations. Focusing on the above-mentioned divisions of the standard, the current study was carried out to ergonomically redesign a production line control panel in an integrated steel industry.

Materials and Methods

Study Design

A sequential exploratory study was conducted, through which hierarchical task analysis and link analysis methodologies were implemented. Participants were initially briefed on the purpose of the research, its voluntary nature and their right to withdraw at any time with prior notice. Ethical approval for the study was granted by the Ethics Board of University of Social Welfare and Rehabilitation Sciences.

Sampling

 Twenty control room operators took part in the study. They were distributed across five comparable control desks, all located inside the main body of the selected industrial unit. The participants were approximately 60\textsuperscript{th} percentile males with mean height of 180 (SD 6) cm, mean age of 40 (SD 7) years, and fit for the duty over the study period. With a mean of 20 (SD 9.1) years of working in control room environments specifically, the participants had also a very high level of industry experience. All participants had more than one year of job experience in the same control room under analysis. The majority of them had a background in either production (55\%) or other instruments (40\%). A much smaller percentage derived from other operational trades (5\%). Sixty percent occupied permanent control room positions, whilst 40\% working on rotational schedules.

Hierarchical Task Analysis (HTA)

Hierarchical task analysis (HTA) is a method of defining goals and tasks for a particular job (using factors such as time, plan, sequence, and status) and dividing each goal into sub-goals, each one with its plans, in order to produce the most effective method of achieving the final aim. Operators' interactions with a specified control panel (Fig 1) were assessed through detailed task analyses. Firstly, all tasks to be evaluated were carefully defined within various scenarios. Then, 15–20-minute video recordings were obtained and time framed. Finally, all essential functions and
Link Analysis

Link analysis is a quantitative and objective method for examining the relationships between interface components, which can be used for optimizing their arrangements. It aims to improve the interface design by examining the task content, the characteristics of each individual item on the interface, and the relationships between them. The cost of each operation in the task is quantified by a link value, which can be a function of importance, frequency, difficulty, and other characteristics of the movements between two elements. The goal of link analysis is therefore to minimize the overall cost, by rearranging the layout while the operator uses the target interface under certain task requirements.

Layout Redesign

The weight of each transition was primarily considered a composite index of frequency and importance. For the frequency, the total usage of each function over the specified 8-hour work shift was calculated as follows:

\[ F_k = \frac{f_k}{\sum_{k=1}^{m} f_k} \]

where, \( m \) is the total number of functions, and \( f_k \) is the relative frequency of usage for function \( k \). Considering the above measures, the link value for each transition from element \( i \) to element \( j \) was calculated as follows:

| E1   | E2   | E3   |
|------|------|------|
|      |      |      |
| E4   | E5   | E6   |
|      |      |      |
| E8   | E9   | E10  |
|      |      |      |
| E14  | E15  | E16  |
|      |      |      |
| E23  | E24  | E25  |
|      |      |      |
| E29  | E30  | E24  |
|      |      |      |

Table 1: Gridded layout of the actual panel
where, $I_k$ is a value reflecting the importance of function $k$ (based on operators' opinions, values ‘1’ and ‘0’ were allocated to “important” and “unimportant” functions, respectively), and $C_{i,j,k}$ is the number of movements from any element $i$ to element $j$ in function $k$. Finally, based on the computed link values, all elements were rearranged within a new control panel layout.

**Results**

A total of eight primary tasks was identified, including four system failure handling tasks, switching between manual and automated modes, and three types of routine vigilance and control tasks. These tasks were broken down into 28 functions and 145 supporting operations, accordingly. Some of the operations comprised simple hand movement between the rest position and a specific element, while the majority involved combinational hand movements within the control panel, too.

In the improved layout (42×60 cm), unusable components were omitted, and elements with inter-related functions were combined and referred to as similar codes (Table 3). Moreover, indicator lights were integrated with the corresponding functional units. The modified arrangement also indicated all computed link values be-

![Table 2: The link table](image)
TWEEN ELEMENTS. DIGITAL MOCKUP OF THE CONTROL PANEL AFTER THE INTERVENTION IS REPRESENTED IN FIGURES 2 AND 3. THE IEC 60073 STANDARD\(^1\) WAS CONSIDERED IN COLOR CODING THE KEYS AND SWITCHES.

**Discussion**

Control panel operation combines cognitive tasks, including visual search, recognition of items, and decision making, with bodily movements. Besides physical and physiological considerations, psychological characteristics of operators influence user experience and performance.\(^{19}\) Accidents and near misses in industrial control rooms reflect operators’ misperception or mental burden, indicating poor design of panels and inappropriate task allocation.

When the control interface is relatively large and physical movements are still required for operating, the accessibility of the control elements with respect to the operator’s position or initial posture may play a more important role than the proximity between them. In fact, such control interfaces are commonly used and being studied in many systems.\(^2\)\(^{-}\)\(^4\)\(^,\)\(^7\)\(^,\)\(^10\)\(^{-}\)\(^13\) In the current study, through an effortless step, a considerable number of unusable elements were excluded, and the control panel shrunk in dimensions. Furthermore, indicator lights were simply combined with corresponding components. This, in turn, allowed the panel surface to be allocated more effectively and efficiently.

Link analysis considers functional proximity while optimizing physical distance and layout in order to achieve minimal mental and bodily effort in using control interfaces, frequently. Cheng, *et al*, proposed an improved link analysis approach to better understand the usability in designing control panel layout.\(^8\) Task and link analyses in this study provided a detailed local insight into the functions and operations involved in interacting with the

| E1 |
|----|
| E4 | E18 | E12 | E12 | E19 | E19 | E14 | E9 | E21 | E11 |
| E29 | E2 | E27 | E27 | E20 | E20 | E20 | E15 | E32 | E33 |
| E8 | E2 | E7 | E7 | E26 | E10 | E16 | E24 | E3 | E22 |
| E28 | E2 | E13 | E13 | E6 | E10 | E16 | E24 | E5 | E22 |
| E17 | E17 | E31 | E31 | E30 | E23 | E25 | E25 | E22 |

**Table 3:** Gridded layout of the redesigned control panel

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**TAKE-HOME MESSAGE**

- Developing consistent human-machine systems is a focal point in ergonomics, being applied to many different areas such as industry, health care, traffic, etc.
- Control rooms can be considered complex socio-technical systems, representing significant levels of human-machine interactions.
- Besides physical and physiological considerations, psychological characteristics of operators influence user experience and performance in interacting with control panels.
Note

mentioned control panel. These approaches thoroughly defined various operational combinations and optimal link values between functional elements within them.

There are limitations in this study. Firstly, although the effectiveness of the intervention was proved theoretically, the definite outcome needs to be practically evaluated through detailed methodological approaches on a functional prototype. Secondly, the gathered data is rather context-specific, and the redesigned control panel would not necessarily fit preferences and requirements in wide-ranging industrial settings.

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Conflicts of Interest: None declared.

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