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The framework for research of operators' functional suitability and efficiency in the control room

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ABSTRACT

Intro: This paper presents the research on operators' functional suitability and efficiency in the Railway Traffic Control Room of the Serbian Railway Company in Niš.
Objective: The objective of this paper is to improve the working abilities of operators, and to achieve more human and rational control room design.
Method: A total sample is n = 41. These are the operators who participated in the ergonomic evaluation of determining factors. A detailed analysis of the functional state of operators and operators' working movements at the control desk was undertaken in respect of the smaller sample of nineteen operators, randomly selected from the total sample. Based on the analytical-synthetic model of research, the ergonomic assessment of functional suitability and efficiency of the operator is formed.
Results: The following results are obtained: the functionality parameter; the time for information search and reading symbols; the symptoms of visual, muscle and mental fatigue of operators; and the number of instruments in the field of view of the operator.
Conclusion: The results of the analysis are used to identify ergonomic recommendations for enhancing the human and technical-technological productivity of work in the control room.

1. Introduction

The research presented in this paper is the expansion of the analytical-synthetic methodological approach, which is applied in various automation systems in Serbia (railway, electric power and mining industry), in order to achieve optimal functional suitability and operators' workplace efficiency in the control centers.

The importance of applying ergonomic rules in the workplace is emphasized in a number of studies (Ayoub, 1990; Blanchard and Fabrycky, 1990; Shikdar and Sawaqed, 2004; Azadeh et al., 2015; and Grozdanovic et al., 2015a). The effects of applying the ergonomic principles are, among others, improved working conditions, balance between human operators and task demands, increased productivity and job satisfaction (Deng, 1999; and Azadeh et al., 2015). Lack of ergonomics rules in the workplace can lead to physical and mental stress, low efficiency and poor quality of job done with increased number of errors (Burri and Helander, 1991; Caldwell et al., 1998; and Cabrero-Canosa et al., 2003). Modern analysis of effects of the human factors and the organization of ergonomic research in complex systems is based on the systems approach (Haines et al., 2002; Kleiner, 2006; and Wilson, 2014). Yun et al. (2000) assess the efficiency and effectiveness of the human factors, with the aid of the integrated checklist and the evaluation procedure, defining the hierarchy of keywords for the evaluation of the critical function monitoring system, where as the top level items, among others, concise display, operability evaluation, recognition, readability, convenient location and display format selection are identified.

The precision of operators' decision-making is influenced by information they receive (Grozdanovic et al., 2015a). There are two different types of control rooms. Conventional control rooms are based on analogue instrumentation and control systems, whereas modern control rooms are based on digital equipment. Ergonomic requirements are important during the system design and the development of monitoring system, improving effectiveness, efficiency, reliability and safety (dos Santos et al., 2013). Although removing human from the decision-making loop by means of

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automation is proposed as the solution for increasing system reliability, the operators must stay in order to control the operations and initiate adequate safety activities in case of an emergency (Meshkati, 2006). Automation does not remove all human errors, but introduces new ones. The changes of the ways in which operators interact with control systems can have negative effects on the work efficiency and decision-making, introducing some new types of human errors (Salo et al., 2006; O'Hara et al., 2002; and Liu and Li, 2014). Design and complexity of modern control rooms and introduced digital equipment influence the workload, the amount of work and reliability of operators, although the main goal of automation is to simplify operators' job and reduce their mental workload (Woods, 1996; Sheridan, 2002; Pickup et al., 2005; Wilson and Norris, 2005; Salo et al., 2006; Ivergard and Hunt, 2008; and Onnasch et al., 2014). An especially demanding task for an operator in the railway control room is alarm handling, involving voice communication with the location where emergency situation with human casualties or major material losses happens (Buddaraju, 2011; and Dadashi et al., 2013).

In emergency situations, a lot of information displayed by the control system can be a burden for an operator and could stop them from making right and timely decisions. The reaction time is decreased if there is a lot of available data. During emergencies, operators are under high stress, and a lot of data cannot help or support operators in making fast and right decisions.

Vanderhaegen defines acquisition, problem solving, and action as the main factors in the behavioral model of operator's unreliability (Vanderhaegen, 2001). Complexity factors in control rooms and high mental workload affect operators' performance, reliability, and system safety (Mattiasson, 1999; Sasangohar and Cummings, 2010; and Gertman et al., 2012). Based on the systems approach, Wilson et al. (2001) developed the Railway Ergonomics Control Assessment Package (RECAP) and tools to assess ergonomics aspects of railway network control. They emphasized the importance of audit (REQUEST tool), situation awareness assessment (RESA tool) and staff loading (RELOAD tool). The analysis of effectiveness of railway control room operators leads to the conclusion that third-shift operators have the highest exposure to fatigue in the railway industry (Gertler et al., 2013). Therefore, the design of the control rooms oriented towards human operator, as the central point, is crucial in interactive and safety-demanding control systems, as RTCRs are (ISO 13407, 1999; and Grozdanovic et al., 2015a). Human factors must be considered and work analysis applied during the development of different display elements and definition of control activities (Cordiner et al., 1999; Crawford et al., 2013; and Dadashi et al., 2013). Reliability and performance of an operator controlling a process are defined by information received and interpreted from the controlled processes, according to data delivered in the control room (Burns et al., 2008). The effects on efficient control, operator's reliability and performance are exerted, among others, by dispatchers' physical abilities (Pheasant, 1996), effective training (Mckee, 1999), properties of display units (video terminals, display panels, and different kinds of monitors), lighting conditions (Lin et al., 2008), workload (Grozdanović, 2003), stress (Desaulniers, 1997; and Lin et al., 2013), fatigue (Popkin et al., 2001), focusing on right data (Nimmo, 2010; and Ivergard and Hunt, 2008), analysis of abilities and limitations of operators (Mckee, 1999), collaborative work and adaptive strategies (Roth and Patterson, 2005; Kauppi et al., 2005; and Jorna et al., 2005), control desk and dispatch console enabling communication with different stakeholders and coordination of their activities (dos Santos et al., 2009; and Grozdanovic et al., 2015a).

Main shortcomings of the previous studies are that problems are described only from the analytical point of view, neglecting problems of synthesis, or the adoption of appropriate ergonomic solutions. Although a number of these studies are quite significant, only a few of them have found adequate practical implementation. The motive of the authors of this paper was to expand the existing analytical-synthetic model with the new research on the psychophysiological characteristics and functional state of operators, as well as functionality of the control desk, with the goal to obtain the new ergonomic assessment of functional suitability and effectiveness in the Railway Traffic Control Room (RTCR) in Niš, Serbia.

2. Methodology

The experimental part of the present study is conducted in the Railway Traffic Control Room (RTCR) in Niš, Serbia. The structure of the main part of the RTCR in Niš is presented in Fig. 1.

A representative sample ($n = 41$) of operators from RTCR is studied, consisting of relatively healthy men between 32 and 55 years of age, whose previous professional activities were associated with the management and control of RTCR. These operators participated in the implementation of the analytical-synthetic model of research and ergonomic evaluation of the determining factors. A detailed analysis of the functional state of operators and functionality of operators' working movements at the control desk is undertaken with reference to a smaller sample of operators ($n = 19$).

According to the presented comments on the factors of reliability of operators in the RTCR, the mathematical, experimental, and other methods are developed. However, the absence of a unified approach results in inability to compare the results of these studies. Therefore, this paper will summarize a large number of factors affecting the reliability of operators classified into four categories:

a) Psychophysiological characteristics of operators, represented by operator's reaction time;
b) The functional state of operators, presented by the research of operator's fatigue;
c) The functionality of control desk, presented by functionality parameter;
d) Functional suitability and efficiency of the workplace, presented by ergonomic assessment of functional suitability and effectiveness of a workplace.

These four categories are identified during the research conducted by a group of researchers on human reliability in man-machine systems at the Faculty of Occupational Safety in Nis in 2013 and 2014. This research was the basis for the expansion of the existing analytical-synthetic model. The detailed explanation as regards the selection and description of these four categories and the reliability of human performance (operators' reaction time, functionality parameter and overall ergonomic assessment) is presented in the chapter “Human reliability in the man-machine systems”, in (Savić et al., 2014, pp.157–193).

2.1. Psychophysiological characteristics of operators

The work of operators in the RTCR can be divided into the following three basic stages: (1) receiving and decoding information; (2) information processing; (3) management of activities. Using the display endpoints, the heights A(a, b) and B(c, d), and the width C(e, f) of the display panel segment controlled by the operator sitting at the control desk 2 (Fig. 1), we can determine visual angles and visual zones. The visual angles in relation to the size display panels are calculated as follows.

Lines p_1 and p_2, which intersect at the eye point EP(x_0, y_0) and pass through the points A and B, are defined by the following

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