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Ergonomic design of crane cabin interior: The path to improved safety

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ABSTRACT

Many procedures in the development process of crane cabins today are still based on the specific experience of manufacturers and historical guidelines. It is not surprising that they fail to meet the needs of a large proportion of operators. Accordingly, the need for more objective, theoretically justified and consistent models, that will minimize crane operators' biomechanical and visual problems through anthropometric characteristic analysis to improve safety and prevent crane related fatalities and injuries, arises. In that aim we firstly identified the critical characteristics of existing crane cabins linked to visibility and posture (seat and armrest problems) using users' opinions and Pareto analysis. We then collected rarely available data on crane operators in Serbian companies (64 in the first and 10 operators in the control sample) and proposed methodology for the ergonomic assessment of crane cabins based on drawing-board mannequins and kinematic modeling. The implemented methodology interval estimate obtains an interior space of 1095 × 1150 × 1865 mm in which is possible to eliminate the critical characteristics of existing crane cabins. The research results fulfill user needs not satisfied in existing crane cabins and suggest certain changes to existing standards on the path to improved safety.

1. Introduction

Cranes, mostly mobile, tower or overhead/bridge cranes (Bureau of Labor Statistics, 2013a and 2013b), are a central component of many construction operations. For decades now the construction industry has been considered as one of the most dangerous among all major industries, being at the very top of the list in terms of the number of accidents and fatalities (Im et al., 2009). In 2012 construction industry had the highest number of fatal work injuries in any industrial sector (Bureau of Labor Statistics, 2013a and 2013b). The reason for that lies in continual changes of working processes, the usage of many different resources, poor working conditions, lack of steady employment, and environments involving noise, vibration, dust, handling of cargo and direct exposure to weather etc. (Pinto et al., 2011). Between 1991 and 2002 there were 7479 fatalities in the construction industry in the United States (Beavers et al., 2006). The Health and Safety Commission made particular reference to the construction industry's problems, with two deaths every week and a fatality rate of six people per 100,000 workers (Sertyesilisik et al., 2010). The HSC's further study conducted in the UK in 2004 found that of the 4624 incidents reported during the five year period, 861 occurred during a lifting operation (Sertyesilisik et al., 2010) while cranes are involved in up to one-third of all construction and maintenance fatalities (Neitzel et al., 2001).

The construction industry is followed by the transportation and warehousing industry sectors and then manufacturing, while financial, information and utilities activities record the lowest rates of deaths and injuries (Bureau of Labor Statistics, 2013a and 2013b). According to Yow et al. (2000) mobile cranes (73%) and bridge cranes (16%) are involved in most accidents.

Given the size and power of available cranes, the potential for loss of property and life involved in utilizing cranes without proper planning and safety procedures is tremendous. A tipped, dropped, or mishandled load can directly injure workers or even potentially upset a critical section of the construction project, possibly resulting in the collapse of the structure itself. This risk of loss is not limited only to those directly involved in construction operations, since there have also been many accidents in which pedestrians were the victims (Neitzel et al., 2001). Construction accidents also obviously have huge cost implications (Lee et al., 2006a, 2006b), while other sectors are not negligible, too.

According to Suruda et al. study (1997) of 502 crane-related fatalities, the leading causes of death in crane operations are electrocution (39%), crane assembly/dismantling (12%), boom

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buckling/collapse (8%), crane upset/overturn (7%), rigging failure (7%), overloading (4%), struck by moving load (4%), accidents related to manlifts (4%), and working within the counterweight swing radius (3%). The subjective opinions of 86% of general site employees show that a crane is the most dangerous piece of equipment found on sites while human error is estimated as the biggest cause of accidents (Beavers et al., 2006). Japan, a country with a very good organizational culture, recorded 41 fatalities resulting from crane accidents in 2006 alone (Tam and Fung, 2011) while the lack of training usually is not the primary cause of fatalities (Yow et al., 2000).

Crane fatalities are not 'freak occurrences'; they are both predictable and preventable while the massive loss of human life is unnecessary (Shepherd et al., 2000). Neitzel et al. (2001) highlighted the need for crane manufacturers to design cranes capable of being safely operated, meeting all applicable safety and design standards, with good maintainability features, and whose typical human factors problem areas should be resolved. The increased technical quality of cranes is the main reason why scenarios such as 'crane instability', 'jib instability' and 'hoisting equipment instability' contribute less to accidents today (Swuste, 2013). According to the Bureau of Labor Statistics (2013a and 2013b), 51% of workers died from unknown causes, indicating possible human factors problems. Also, crane operators remain in cabins for the whole day. Tight construction schedules usually hinder the implementation of construction site safety (Mohamed, 2002). The space within the cabins is sufficient for only 18.5% of operators, while 28.9% of them feel extremely uncomfortable (Tam and Fung, 2011). Although previous research demonstrated that 42% of all incidents are linked to the design for safety concept (Gambatese et al., 2008), very little research has been done in the field of the assessment of the anthropometric convenience of crane cabins. The importance of studying this problem greatly exceeds the attention devoted to it in previous research studies in this area.

1.1. Objectives and scope of the study

The high rates of construction injuries and fatalities associated with cranes clearly indicate that current design and safety procedures and devices are not effective enough in preventing accidents (Neitzel et al., 2001), pointing to the need for more objective, theoretically justified and consistent models. Relevant body measures are influential in determining numerous aspects of physical interactions between users and products (HFES 300 Committee, 2004), so if a product is to be successful in meeting the needs of certain user group, product designers must use specific information about that user group. This paper aims to define new procedures in the crane cabin development process and to facilitate interaction between operators and cabins by using information on user needs and the collected anthropometric data from Elektroprivreda Srbije hydropower plants, which are undergoing revitalization and reconstruction over the last few years.

This paper focuses on the following objectives: (i) to identify user needs through the critical characteristics of existing crane cabins according to users' opinions using Pareto analysis; (ii) to propose methodology for the ergonomic assessment of crane cabins; (iii) to examine and verify the results of such ergonomic assessment; and (iv) to give recommendations for improving safety performance related to ergonomical crane cabin design.

This paper empirically tests 23 crane cabin types and is based on the anthropometric data of 74 crane operators. After the introduction in Section 1, Section 2 gives the literature review. Section 3 presents the ergonomic design of the crane cabin methodology and results. Section 4 gives the discussion with recommendation for future design, while Section 5 presents the conclusions.

2. Review of the literature

The safety issues pertaining to cranes are described in detail in the introduction, so herein we will deal with issues connected to ergonomics. Literature in the ergonomics field is very narrow; all surveys with the exception of Ray and Tewari (2012) and Nordin and Olson (2008) are in other fields only touching physiological issues.

Chandler (2001) prepared guidelines covering all standards for overhead crane cabins in the aim to help in reduction of the potential for human error due to design and thus connecting ergonomics and safety issues. His main aim was to aid human factors engineers in evaluating existing cranes during accident investigations or safety reviews.

Sen and Das (2000) analyzed the cabins and hooks in 51 electric overhead travelling cranes in a heavy engineering factory and noticed that control-movement compatibility was absent in most of the cranes, making the operators' job even harder. Crane operators also frequently control more than one crane per shift and incompatibility makes their job more stressful.

Operating a crane demands a static sedentary position with hands held steady on the operating handles with frequent body twisting, deep sideways bandings and exposure to vibrations that are risk factor for lower back pain. Beavers et al. (2006) highlighted the problems with the seat, visibility, noise, commands, access to the cabin etc., but did not analyze them further. Burdorf and Zondervan (1990) carried out a survey among 33 crane operators in a steel factory and recommended persons with a history of back complaints not to seek employment as crane operators. On a sample consisting of 46 crane operators Bovenzi et al. (2002) found that 40–60% of operators with 12-month prevalence have lower back pain. Kittusamy and Buchholz (2004) also concluded that awkward posture during the operation of heavy construction equipment is a consequence of improper cab design and work procedures, emphasizing poor visibility of the task, limited room in the cab, excessive force required to operate levers/pedals, and improper seat designs, as some of the characteristics of a poorly designed cab.

Tall crane operators are probably the most vulnerable workers. Carragee et al. (2008) synthesized the literature and presented the fact that among workers in manual occupations, the annual prevalence of neck pain varied from 16.5% in spinning industry production line workers in Lithuania to 74% in Swedish crane operators, who are among the tallest in Europe.

All previously discussed surveys do not include any anthropometric analysis.

Knowledge of human anthropometric characteristics is a prerequisite for a good understanding of the fit between man and machine and for the biomechanical design of any work system, too (Hsiao and Keyserling, 1990). One of the surveys in the narrow field of this paper carried out by Ray and Tewari (2012) studied 23 body dimensions of 21 crane operators in order to minimize the anthropometric mismatch within the enclosed workspace. They found many misfits of even the 50th percentile crane operator population on site with the existing work system (Ray and Tewari, 2012). Using the example of the crane cabin manufactured by MacGREGOR which operates in Sweden, Nordin and Olson (2008) discussed crane operators' comfort and reached the conclusion that the given cabin was not suitable for the majority of the population.

Unfortunately, many procedures in the development process of crane cabins are still based on the specific experience of manufacturers and historical guidelines that are often arbitrary and subjective, hence the need for new objective, theoretically justified and consistent models.

Previous research points out the need to increase the well-being and facilitate the interaction of crane operators to eliminate