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

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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 were electrocution (39%), crane assembly/dismantling (12%), boom...
buckling/collapse (8%), crane upset/overturn (7%), rigging failure (7%), loading (4%), stuck 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
discomfort and consequently accidents at work through anthropometric characteristics analysis. This would serve to improve safety and prevent crane related fatalities and injuries.

3. The ergonomic design of the crane cabin interior: methodology and results

We will start the ergonomic design of the crane cabin interior from user needs analysis on Nordin and Olson (2008) data on 6 cabin types in Sweden followed by a new sample of 17 cabin types in Serbia in order to find the critical characteristics of existing crane cabins. The collected anthropometric data on a sample consisting of 64 crane operators then will be used to comfortably accommodate the highest possible range of anthropometric measurements between the 5th and 95th percentiles of crane operators, through methodology based on mechanical mechanisms to fulfill user needs not satisfied in existing crane cabins. The second sample containing 10 new crane operators from Serbia will serve to prove our methodology and provide recommendations for designers. The methodology is shown in the flow chart in Fig. 1.

3.1. The critical characteristics of existing crane cabins

In order to improve working conditions for crane operators, it is necessary to determine the goals and criteria for the improvement of contemporary crane cabins first. Benchmarking is the method that enables organizations to identify the key processes/characteristics that need improvement (Fernandez et al., 2001). Understanding user voice and enhancing design characteristics to meet user needs not satisfied in existing crane cabins is very rare in the available literature, and one of the few methodologies and results providing the critical point of initial ergonomic analysis (more detailed than that given in Nordin and Olson, 2008). The content of Kittusamy's list and its capacity for assessing errors in cabin design make it a suitable reference tool for the assessment of designer solutions in cranes and heavy mobile equipment (scrapers, dozers, backhoes, and loaders). A data check-list with 32 questions was applied to 17 types of crane cabins located in Serbia manufactured by domestic and international producers and their operators filled it (17 persons from our larger sample were willing to complete the list and give interviews). The negative percentage index was calculated on the data collected in Serbia so as to show the percentage of possible improvements according to the parameters defined by the questionnaire. Kittusamy and Spokane (2003) proposed overall total cab score calculation on the collected data to compare producers, but not to identify the top portion of causes that need to be addressed so as to resolve the majority of problems. Therefore, in this survey Pareto analysis was performed for the latter in order to show what causes the majority of problems. Results show that the largest part of problems is caused by armrests (13.6%), starting from whether they are available at all, and, if so, whether they are placed at an appropriate height and whether they are adjustable. Then follow the problems of vertical and horizontal seat adjustability (12.8%). The negative index ranging from 10% to 12% includes questions referring to the lumbar support of the seat, whether it can be tilted backward and whether it can swivel. This category also comprises temperature control by the operator. The negative index value from 5.5% to 10% includes problems such as whether the seat has initially been set at an appropriate height, whether the controls or levers are easily reachable and easily operated, whether there is sufficient upward visibility and if the view of the operation is obstructed, whether the general overview of the ground zone is good and whether there are distracting reflections from the cabin windows.

The results of the needs analysis on the samples of crane cabins operating in Sweden and Serbia indicate the need to conduct
further ergonomic analyses using anthropometric measurements, especially when we bear in mind the fact that tall crane operators are probably the most vulnerable workers (Carragee et al., 2008). It should be particularly emphasized that the Swedish population has the largest average height and Serbs follow in the European region.

3.2. The anthropometric accommodation of crane operators: workspace modeling

A well-designed crane cab not only makes a significant difference to the operator's working conditions, but also affects the safety on sites where cranes operate. Today there is a pressing need to enhance ergonomic cab designs for safe and efficient operation due to high incident rates that are the logical consequence of the unresolved ergonomics problems as our survey has shown. Up-to-date anthropometric data play a key role in their design. Unfortunately, although Pareto analysis in the previous section has shown that the critical characteristics of cabins are not appropriately designed, anthropometric data on the crane operator population have rarely been collected in the past.

Our aim, by limiting the interior space, is to accommodate the highest possible range of crane operators' anthropometric measurements between the 5th and 95th percentiles (as the traditional, most widely used design criterion and economical choice according to Helander, 2006) so that they have both comfort and safety when operating the crane. According to Klarin et al. (2009 and 2011), with certain adjustments, 99th percentiles can also be accommodated in that interior space (as shown in Fig. 3). As proposed by Vogt et al. (2005) and proved in our survey, the Klarin et al. (2009) concept, with fixed heel point, is closest to common seating concepts and economically justified in all designs where foot controls exist. Since crane drivers also use foot controls, the main hypotheses of this research are:

**H1.** The crane operator and the cabin form a system with numerous interactions, whose origin of the coordinate system, as the starting point for dimensioning and construction, is the fixed point of the crane operator’s heel on the cabin floor behind the foot pedal.

**H2.** Other dimensions important for dimensioning the crane cabin are further determined by the movement of anthropometric measurements according to the kinematic mechanism principles.

The profession of a crane operator is quite specific and requires special selection and training. The share of crane operators in the general Serbian population is quite low. Hence, our first sample comprised 64 participants. All participants were male, with an average age of 47.64, with standard deviation of 10.34 years.

Measurements were taken in several Elektroprivreda Srbije hydropower plants located throughout Serbia, where a large number of cranes are stationed (types common for both construction and industrial sites: overhead/bridge, mobile, tower, and gantry cranes with cabins). Elektroprivreda Srbije hydropower plants have undergone revitalization and reconstruction over the last few years, executing both construction and other industrial works. Accordingly, these sample characteristics ensure the intended representativeness. The sample was formed by means of the static anthropometry method, which implies measuring in the erect position during standing and sitting (so that the torso is at a 90° angle with the upper leg, and the upper leg at a 90° angle with the lower leg). As can be seen in Table 1, a total of 9 basic static anthropometric dimensions including weight were recorded for each individual: Stature (mm), Seat height (mm), Upper leg height (mm), Lower leg height (mm), Shoulder breadth (mm), Hip breadth (mm), Arm length (mm) and Shoe length (mm). Shoe length was chosen due to the fact that operators use pedal controls in shoes. The standard anthropometric instruments used in this study were an anthropometer, a beam caliper, sliding calipers, and steel tape. Other instruments included a weight scale and a stool for seated measurement. The participants remained in their clothes and shoes during the measurement. To ensure data quality, we trained 3 measurers prior to data collection (inter-rater variations minimization) and the measuring team repeated the measurements on participants until the inter-observer differences were at or below the levels specified in Gordon and Bradtmiller (1992).

Table 2 illustrates the correlation coefficients obtained between the analyzed dimensions. Approximately 60% of the correlation coefficient values obtained are significant at the 5% level, while the remainder are non-significant. The highest correlation coefficients were found between stature, lower and upper leg heights, and seat heights as well as between hip width and BMI, which is a more appropriate measure then weight.

Figs. 2 and 3 illustrate the average values obtained for two different anthropometric dimensions according to the defined age groups. These show that dimensions vary significantly with age, and, as can be seen, crane operators lose height and gain more weight over the years. It is also interesting to compare these results with other anthropometric data in Serbia (only our surveys about car drivers are available) which show that the hip width of the 95th percentile car driver in Serbia is significantly lower and has an average value of 420 mm (Klarin et al., 2008) compared to 491.4 mm value in crane operators. That is probably caused by the nature of the crane operator's job which involves long periods of sitting. In addition, the seat height of car drivers in the range between the 5th and 95th percentiles is 852–994 mm, while for crane operators it is 806–981 mm. This ratio for the shoulder breadth of car drivers is 403–534 mm, and for crane operators 391–543 mm.
We have already applied the methodology of workspace modeling in car driver interior space design in Klarin et al. (2011) which is similar to that described in Hamza et al. (2004). The modeling of the cab construction starts by adjusting the elements of the human-cabin system to comfort posture, along with fixing the origin of the coordinate system. Vogt et al. (2005) suggested fixing the joint visual angle or operator’s hip for the heel, hip or hand. All non-fixed body points generate an accumulation of points whereby a field is defined. The crane cab requires the construction measured in the coordinate system with the fixed point in the operator’s heel, which is in front of the foot pedal. Fixing the zero coordinate point is enabled by the kinematics of heel movement, as shown in Fig. 4, which for large legs and feet, due to seat movement backwards and downwards, moves the heel relatively toward the front along with an increase in the foot’s angle with the floor (command). In the opposite case, this is achieved by moving the heel, e.g. in small anthropometric measurements, toward the back and reducing the angle between the foot and the floor, along with an increase in the angle between the lower and the upper leg, as well as between the upper leg and the seat height (torso), all aimed at the maximum overlapping of visual angles for 5th to 95th percentile males.

Hence, our dimensioning methodology has three basic postulates based on functional anthropometry, which is task oriented:

1. The construction and dimensioning of the cabin start from the origin of the coordinate system at the fixed point of contact between the crane operator’s heel and cabin floor in front of the foot pedal next to the right foot, as already used in other surveys that also use pedal controls.

![Fig. 4. Heel point (a) and foot movement (b) of 5th – percentile and 95th – percentile man.](image_url)
2. The visual angles for the whole predicted range of operators with the criterion of the smallest possible deviation cannot be the same, but they are dimensioned to the minimum of 60°, because the downward viewing angle is about 60° below the horizontal line (Anshel, 2002 and Nemeth, 2004).

3. The remaining space is dimensioned in line with large anthropometric measurements ranging from 5th to 95th percentile operators, corresponding to the movement of a mechanical mechanism, i.e. complying with the kinematics of movement, which is described in detail in Klarin et al. (2011).

Drawing-board mannequins are used to estimate the best work location for a given task (as proposed in Armstrong et al., 1986). Using the pattern of body segments, shown in Fig. 5 for the drawing-board mannequin, as well as the data from Tables 1 and 2, we were able to obtain a vertical projection (in the z-x plane) of the space necessary for placing the crane operator in the cabin through kinematic modeling, as shown in Fig. 6.

Fig. 6 shows that the visual angle of 60° when looking downwards is possible for the range of the 5th to the 95th percentile operators, which overlaps in two extreme positions, where the hip joint angle for the 5th percentile is 87° while for the 95th percentile angle amounts 104°. According to Nemeth (2004) the normal human visual field extends to approximately 60°, so there is no impact on the neck. The optimal angle of the seat surface has
been enabled in all positions, so that the femur is horizontal, and the hip and the seat surface form an angle of 7°. The arm span for using manual commands for both positions of the 95th percentile operator, in accordance with the head position and movement, horizontal and vertical seat adjustment and other dimensions and angles, from the shoulder joint (semi-center of rotation) to the hand with folded fingers is 764 mm. For the 5th-percentile operator who is in position III with reach 3, the arm span is 616 mm, but the part of the field shaded in Fig. 6 cannot be used in this case since it is outside the haptic field of the 95th-percentile operator. The arm flexibility of the 5th percentile operator enables normal work and use of commands within the reduced field. The chair should be adjustable 200 mm horizontally and 100 mm vertically. The minimum total height of the interior and cabin door should be equal to the stature of the 95th percentile operator in shoes with clothes (Bridger, 2008), e.g. 1850 mm in order for comfortable entry into the cabin. Further headroom space is not considered because operators work in a sitting position. The length of the seating surface of 400 mm and the height of the backrest are determined by the anthropometric measurements of the 5th percentile operator.

In the z-y plane, the y-axis dimensions are determined by the shoulder and hip breadth and arm and leg haptic fields. The shoulder breadth for the 5th percentile operator is 391 mm, and 543 mm for the 95th (according to Table 1). The hip breadth for the 5th percentile operator is 290 mm, and 490 mm for the 95th percentile operator, which is significantly higher than the average for the Serbian population or other professions. The seat height should be vertically adjustable from 625 mm to 735 mm, implying a range of 110 mm, with the horizontal movement of 50 mm. The problem of the armrest height is reduced to a compromise between the requirements of standard ergonomics and the need to use both hands simultaneously. The ergonomics of arm movements during work requires the placement of the work object in the optimal haptic field, which means that the field at elbow height with the upper arms hanging loosely next to the body, while the angle between the lower arm and the upper leg is 90°, while forming arches in the horizontal plane of the left and right arm. The intersection of the fields of both arches directed toward the body is the optimal haptic field. Since in this case the position of the commands would obstruct the visual angle they need to be separated into consoles, which also serve as armrests. The armrest and the seat should be adjustable, both in terms of height (z-axis) and length (x-axis). The position of the backrest with the commands is restricted by the maximum arm span, bearing in mind that the field within the optimal visible visual angle of 60° should be discarded. The next restriction refers to the depth of the chest of the 5th percentile operator, and hence the command should have a vertical axis on the straight line x = 200 mm. The backrest position in relation to the seat surface is the result of two movements: movement due to differences in seating height and owing to the difference in the height of the bent elbow for 5th and 95th percentile operators. Hence, the two final positions of the backrest separated by 210 mm are obtained and marked by the thick line in Fig. 6. The same method was used to obtain the basic dimensions of the crane operator’s work chair in the x-y plane, shown in Fig. 7.

The final minimum interior space crane cabin dimensions, based on normal operational requirements and adequate room for operator comfort and safety according to anthropometric measurements in Serbia, were obtained as projections of 5th and 95th percentile mannequins on the x, y and z axes in Figs. 6 and 7. According to the point estimate, the dimensions of the enclosure space (interior space for the comfortable work of crane operator) amount to 1080 × 1100 × 1850 mm. Using interval estimates and when rounded up to integer numbers the space dimensions are 1095 × 1150 × 1865 mm.

A system of mounted cameras and visual display units may solve obstruction problems which interfere a clear view of the task and cause poor visibility in certain operator fields (Wilson, 1995), since the already maximized visual angles still have obstructions. As proposed by Lee et al. (2006a, 2006b) a video camera could be installed on the crane and a device developed to transmit visual signals to a monitor installed in the operator’s cab on the crane, or cutting-edge wireless video control, RFID and GPS technology could be introduced. The operator would be able then to control the picture on a color LCD monitor and navigate through different zoom modes as required (Yang et al., 2011). Shortening individual cycles due to a better vision system ultimately adds up to a shorter working time for the crane and shorter delays caused by the denial of crane service to noncritical activities (Yang et al., 2011). By allowing the crane operator to continuously view the theater of work, the system prevents accidents and enhances work safety, while night shifts are possible, too. Signalmen are no longer necessary either. The proposed solutions require space in the cabins’ right angle with three degrees of freedom, which enables all movements such as vertical, horizontal, and rotation to match the operator’s diverse physical positions when using cameras/display system.

3.3. Results validation

The second sample data of 10 crane cabin operators given in Table 3 were collected in Serbia in 2013 using the same method as for the first one, to serve for modelling verification. The operators from the control sample could be placed in the first sample’s enclosure space and all the participants in the control sample were found to be within the space limits. In that way, the used methodology is validated.

Finally, it was also proved that a satisfactory working environment and greater employee safety for crane operators can be achieved after the proposed ergonomic adaptation.

4. Discussion

The most frequently used recommendations from available standards and manufacturers’ arbitrary historical guidelines should be partially modified in keeping with the findings of this
research in order to increase the operator’s comfort in the following way:

- There is a change in the range of the seat height adjustment upwards and downwards from 152.4 mm (according to Chandler, 2001, to improve crane cabins used in Boing) to 100 mm in this survey, while the increment remains no more than 30 mm. Producers of ergonomically adapted crane cabins such as Brieda, however, have a range of 90 mm (from 352.5 mm to 627.5 mm).
- The seat width should range from 450 mm to 510 mm, as proposed in ISO 8566-5 (1992), which according to our results, has an exact value of 490 mm.
- The seat length is not in accordance with ISO 8566-5 (1992), and this survey comes to a result of 400 mm.
- The seat should have waterfall edges (this recommendation remains as given in Chandler, 2001).
- The seat should slope backward from 0° to 7° (it should not be fixed at 7° as given in ISO 8566-5 (1992)).
- The original backrest size was 381 to 508 mm high according to ISO 8566-5 (1992), while the results now demand 550 mm. The width of 300 mm to 360 mm, according to ISO 8566-5 (1992) should be increased to 380 mm. A width of 380 mm enables maximum torso mobility and movement greater than 180° when required.
- The seat should have five supporting legs or be attached to the cab floor and provide adjustable seat positioning toward the console. The swivel chair with supporting legs should have a seat base of 457 mm (this recommendation remains as given in Chandler, 2001).
- The armrests should be undercut to allow enough space for the hips and thighs.
- The armrests should be adjustable in the range between 220 mm and 280 mm instead of the previous 190 mm and 297 mm according to ISO 8566-5 (1992).
- The armrests should be 120 mm to 200 mm in length instead of the recommended 203 mm according to ISO 8566-5 (1992).

Table 3

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Shoe length (mm)</th>
<th>Statute (mm)</th>
<th>Sitting height (mm)</th>
<th>Lower leg height (mm)</th>
<th>Upper leg length (mm)</th>
<th>Shoulder width (mm)</th>
<th>Hip width (mm)</th>
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</table>

Our sample was considerably larger than all of the samples used so far. Burdorf and Zondervan (1990) used a sample of 33 participants, Bovenzi et al. (2002) of 46, and Ray and Tewari (2012) 21. If we compare this data to available research in the field, the mean and standard deviation values for the height of crane operators in Serbia of 1750.30 and 59 mm in the first and 1782 and 42.25 mm in the second sample or 1754.65 and 58.27 mm for both, are close to the values of 1765 and 74 mm obtained by Burdorf and Zondervan (1990) on a smaller data sample in the Netherlands, and to those of 1780 and 68 mm gained by Bovenzi et al. (2002) also on a smaller set of data in Italy.

The methodology applied on the sample of Serbian crane operators may serve to eliminate the critical characteristics of existing crane cabins obtained through Pareto analysis (the majority of problems are caused by armrests, seat adjustability, seat lumbar support, the reachability of controls or levers, and visibility). The new cab construction makes it possible to have adjustable armrests placed at an appropriate height (according to our survey, the existing cabs had the highest negative index of 13.6%). The seat problems have also been resolved in terms of both height and width (a negative index of 12.8%). It is also necessary to provide seat lumbar support, the option of swiveling and turning (a negative index of 10–12%), as well as the ability to control the cab temperature. In addition to enabling the largest possible visual angle, load visibility problems should also be solved by setting up a system of monitors and cameras, which can be initiated by the operator when the load is outside his visual field. Usage of transparent material for most of the lateral parts of the cabin and a significant part of the floor ceiling is recommended in order to improve the operator’s visibility when the vision system is not in use. The vision system, when implemented, can allow the operator to observe the results of the tasks he is controlling and enable him to make correct decisions based on accurate information perceived, without turning the head to the left or right more than 30°, i.e. tilting the head more than 5° up and more than 25° down (Barron et al., 2005). In Dondur et al. (2012) the economic feasibility of the production and use of new generation crane cabins with the problem of visibility solved through video control was already analyzed. Such cranes will allow higher productivity due to the reduction of the physical and psychological stress of the operator, as well as greater safety and security thanks to the integrated visual system. Dondur et al. (2012) also proved that the total economic benefit of the exploitation of the cabin in the overall exploitation period is significantly higher than the purchase price – the internal rate of return is above the relevant weighted average interest rate and the payback period is less than three years, so the project fits into the very low risk category. All previously mentioned design solutions are expected to solve the problems identified by the operators in this survey thus improving the critical characteristics of crane cabins and impacting positively on safety.

5. Conclusions

Despite being the cause of large numbers of accidents, crane cabins today are not designed in accordance with operators’ anthropometrics. Therefore, the starting point in this paper is the data gathered about the anthropometrics of the operator sample which significantly differ from the data of the general population. Research into the operators’ needs then follows in order to identify the significant problems by means of Pareto analysis. Later, a number of problems, such as how to minimize or remove the anthropometric mismatch, how to enhance the workspace visibility for a crane cabin operator in an enclosed workspace, and how to
improve work posture thus minimizing the risk of musculoskeletal disorders by applying ergonomic principles, have been solved through modeling crane operator workspace. The usefulness of the methodology used in addressing and solving these problems and the quality of the solutions obtained are verified on the second sample of crane operators. All operators from the second sample are accommodated in the proposed interior space of 1095 × 1150 × 1865 mm thus validating the methodology. The methodology is expected to be used in the future on new samples of crane operators in different geographical regions so as to confirm our expectation that shorter persons are accommodated more easily. Also, the application of our recommendations in design should have a number of benefits, such as the increased enthusiasm of crane operators, a reduction in work-related pain and injury risk, an increase in the comfort and efficiency of crane operators, and an increase in overall system productivity and safety.

It is also possible to use the procedure implemented in this research study for modeling other professions.

The existing cabs were evaluated from the operators’ space requirements and their field of vision, while further investigations should be made in order to test noise, vibrations, luminance, temperature and air humidity. Controls also give sufficient room for future research.

There is also a need for extensive surveys focusing on both male and female crane operators in different regions in order to generate region specific anthropometric databases for the further safe and efficient design/modification of crane cabins with harmonizing all collected data.

The percentiles are univariate (one-dimensional) statistics applied to multivariate situations, so future research could also deal with that fact and apply multivariate statistics.

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References


