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RESEARCH ON ACCIDENT SITUATIONS OF CRANE TRANSPORT SYSTEMS

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Abstract: Although in recent years more and more attention is paid to risk-based maintenance techniques and technical diagnostic methods are being implemented on an ever-increasing scale, cranes still participate with as much as one third in all deaths in certain types of industry. In line with that, the subject of this research is the verification of an instrument for the investigation of accident situations of the crane transport system. After conducting a factor analysis and reliability analysis, it was confirmed that the instrument with 8 dimensions of different weight factors can be used as valid and reliable. Data were collected in 51 domestic companies, where crane transport systems are used. The mean value of collected data shows that the examination of accident situations of the installed crane transport system is at a very low level in the domestic industry - 18.95 out of 75 points. The proposal of further research is to link the obtained data with other variables that affect the operation of the crane transport system, such as the commitment of management to risk management, training of maintainers and operators, prescribed work procedures, process safety information, change management, occupational safety and machine inspection procedures.

Keywords: crane transport system, risk, accident, factor and reliability analysis

1. INTRODUCTION

Cranes are extremely widespread group of machines, fundamental for transport processes in the construction, process, production and many other types of industry. (King, 2012). They are very massive, load can be dropped or mishandled and as such can pose a danger to human life and cause significant material damage. (King, 2012; Milazzo et al., 2016; Spasojevic Brkic et al., 2015; Brkic et al., 2015). Accordingly, previous research estimates the cranes cause a third of fatal accidents out of the total number of accidents occurring in the construction industry (Brkic et al., 2020). The consequences of accidents caused by the operation of cranes, in addition to material damage, sick leave and reduced employee motivation, often include injuries at work and/or deaths of employees in the immediate vicinity of the production plant or construction site (Zrnić et al. 2011; Pratt et al., 1997; Brkic et al., 2015). For this reason, it is necessary to study in more detail the causes of accidents on construction sites so that they can be successfully predicted and prevented. In order to do that, it is necessary, first of all, to collect data, but not only on data on previous accidents, but also to make a detailed analysis of work procedures and accident research.

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After that, it is necessary to adequately process the data in order to draw valid and reliable conclusions. In this paper, factor analysis of data collected by survey companies in the Republic of Serbia that use crane transport is presented, as the very first step towards reducing the number of accidents on sites where cranes operate and a very important factor that will determine the further course of research.

The paper after introduction in the second section provides an overview of previous research related to the number of fatal accidents in the world. The third section gives a detailed description of survey which was performed, followed by an exploratory factor analysis in order to reduce the dimensionality of the space, with the application of “varimax“ rotation when it is necessary. At last, in the fourth part conclusions and future research avenues are given.

2. PREVIOUS RESEARCH

In the available literature, researches dealing with factor analysis of data obtained by surveying companies that use crane transport are rare. The research conducted so far relates primarily to the number and causes of accidents that have occurred on construction sites around the world.

According to that, there is research that based on data from the U.S. Bureau of Statistic for 2006, 72 deaths of workers where registered during accidents sampled by crane operation. Between 1997 and 2006, there were 818 deaths in the crane accidents in the United States of America (Arnold & Itkin, 2019), while between 2002 and 2006 in U.S.A. Texas leads with 27, then California with 25 and Louisiana with 17 fatal accidents (Arnold & Itkin, 2019).

Non-compliance with crane manufacturer’s regulations regarding loads and other restrictions is generally considered to be the main cause of accidents (Arnold & Itkin, 2019). The main causes of crane related accidents are (Arnold & Itkin, 2019):

- use of the crane for needs that are outside the production specifications and inadequate choice of crane,
- extreme weather conditions,
- improper crane set up,
- falling debris and other dangerous conditions around the crane,
- contact with transmission lines.

Wiethorn (2014) conducted a study of crane accidents in 49 U.S.A. states, South Africa, Brazil, Canada, the Bahamas, Puerto Rico, and the Virgin Islands and created a large database. The database records 716 accidents in the period from 1983 to 2013 years. By further analysis of the data collected in the database, Wiethorn (2014) observed the structure of primarily and secondarily responsible persons responsible for the accidents. Primarily responsible persons are defined as persons who, if they did not violate their responsibilities (did not perform their responsibility properly), the accident would not have occurred, while secondarily responsible persons are considered persons who have violated their responsibilities, the accident would have worsened, but its occurrence regardless of other factors. In the 94% U 94% of crane accidents, the human factor had an impact.

Shin (2015) also considered accident causes for construction tower cranes. The research was conducted in Korea, and included 38 construction tower cranes, in the period from 2001 to 2011 years, in which fatal accidents occurred. In the observed accidents, 53 people were died, while 15 were injured, which is a total of 68 victims. According to the phases of work, it was determined that 36.8% of deaths occurred during installation (climbing), and 18.4% during the dismantling phase. The highest percentage of accidents, 68.4% occurred during installation/dismantiling, while 18.4% occurred during normal operation.

Tomakov et. al. (2018) conducted research on the causes and consequences of crane accidents in Russia. According to their data, in 2016, 76,832 companies and organizations were monitored, and 725,000 different types of lifting equipment were recorded. Of this number, there were 200,113 lifts on 24,086 cranes and construction tower cranes.

During 2016 (on all lifting equipment covered by the research), 62 accidents were recorded in which 38 people died in 2015 there were 59 accidents and 58 people died. For the same accidents, 16 were injured in 2016 and 21 injured in 2015 (Tomakov et. al., 2018).

During 2016 in Russia, there were 42 accidents that occurred only during the operation of cranes, while 1 accident occurred during lifting (construction tower crane), 2 during the installation of cranes, and one when working with a cable car (Tomakov et. al., 2018).

Raviv et al. (2017a) analyse 51 accidents and 161 near misses and report on qualitative and quantitative analysis methods for a structured investigation of tower-crane-related incident stories (near misses and accidents) and come to conclusion that technical failures are the most hazardous risk factors within the tower crane domain, while failures related to the human factor were found to be only second to those related to technical factors. The same authors in (2017b) implement the analytic hierarchy process (AHP) to evaluate the quantitative outcome severity level values on data collected from near-miss reports and find a direct relationships between technical factors and the magnitude of their risk potentials, and inverse relationships between human factors and their risk potentials.

The survey Brkic et al. (2020) analyses accidents caused by crane operation from 1985 to 2018 year in 71 countries, with the aim of determining the frequency of injuries at work and deaths in each country individually and isolating those with the highest number of accidents, which results in one of the two outcomes, using Pareto analysis. Pareto analysis shows that 80% of fatal accidents occur in the following countries: Romania, China, Turkey, Bulgaria, Poland, Israel, Croatia and Spain. The main causes of accidents involving cranes using Pareto analysis identified machinery (including construction), inadequate use, assembly/disassembly and transport of the crane because 80% of accidents are due to their causes. Proposed further research, according to Brkic et al. (2020) is a detailed analysis of the role of the human factor in the dominant causes of accidents.

Previous research definitely points to the necessary analysis of the human factor, so this paper covers the effect of the human factor in the accident investigation process.

3. SURVEY DESCRIPTION

The survey instrument - questionnaire was sent by e-mail to 60 companies in Republic of Serbia, which use the crane transport system. Although official data is not available, the population of companies with a crane transport system, according to the authors of the survey and five surveyed experts, is not significantly larger. After three sending of the survey (initial sending and two reminders – requests to conduct the survey), during three months, 51 companies responded (whit an average of 122 employees). Unexpectedly high response to the survey was noticed, 85%, which shows a very high degree of interest of the respondents in solving problems in the crane transport system.

The average number of employees in the surveyed companies is 159.85 with a standard deviation of 247.12. The survey was completed by experienced employees, with an average of 18.25 years of work experience. The surveyed companies have ISO 90000 certification in 73%, ISO 14000 in 47% and ISO 18000 in 51% of cases, while 42% of companies points out that they have an integrated management system for all three standards.

Table 1. Questionnaire layout

10	Question	Possible result	Real result
10.1	Is there a procedure for investigation the cause of incidents/accidents?	10	
	Does the procedure require the application of research findings of prevent new similar incidents?	5	
10.2	Does the procedure require the examination team to include:		
	a. A member trained in incident investigation techniques?	3	
	b. A member acquainted in detail with the process of operation of the crane transport system?	3	
10.3	Is there an accident/incident record that includes the following information?		
	a. Date of incident	1	
	b. Incident investigation start date	1	
	c. Incident description	5	
	d. Identified causes of the incident	5	
	e. Evaluation of potential hazards and probabilities frequency of occurrence	5	
	f. Recommendations needed to prevent the incident	5	
10.4	Based on the history of failures, does it can be seen that the envisaged procedures for investigation the incidents of the crane transport system are being applied?	5	
10.5	Is adequate staff (engineers, crane operators…) involved in the analysis of incidents/accidents that occurred due to failure of equipment components of the crane transport system, in order to discover the cause of failure?	10	
10.6	Are all incident/accident investigation reports submitted to the suppliers of the crane transport system and is there a written procedure by which the suppliers undertake to prove that the incident did not occur through their fault?	7	
10.7	Have all incident reports of one crane transport system in the last year been forwarded to all other organizational units using the same or a similar crane transport system?	4	
10.8	Does the incident investigation procedure require that its findings be included in future risk analyses?	6	
	TOTAL POINTS	75	

4. FACTOR AND RELIABILITY ANALYSIS

Table 2 shows the calculated mean values and standard deviations for each question from survey.

Table 2. Mean value and standard deviation

Question	Mean Value	Standard Deviation
10.1	1.053	3.223
10.2	0.368	1.116
10.3	7.632	4.536
10.4	1.421	5.113
10.5	4.947	2.147
10.6	2.895	1.100
10.7	0.158	0.688
10.8	0.474	1.429

The primary goal of factor analysis is to compress the information contained in the original variables into a smaller set of new composite dimensions with minimal loss of information, respectively retaining a sufficient amount of information. Consequently, one of the main reasons for applying factor analysis is the law of "savings" or parsimony, which allows a larger number of variables to be explained using as few sets of variables as possible, without significant loss of information (Hair et al., 1998). The aim of factor analysis is also the selection of factors describing the construct, which should be based on previous research, if any, and it is desirable to confirm the proposed fators by several experts (Cattell, 2012; Kline, 2014). The main goal of factor analysis has two lower level goals:

a) reducing the dimensionality of the original space by factorization procedures and
b) determing the connection between the constructs and the factors that describe it.

The sample size required for factor analysis is at least 50, and preferably 100 or more observation units (Cattell, 2012; Kline, 2014; Hair et al., 1998; Joseph et al., 2010). In the interpretation of factor analysis, it is very important to consider the total variance of variables explained with retained components, while the comunality of an individual variable speaks about how much variance of a certain variable is explained with retained components (Cattell, 2012; Kline, 2014). Also, if groups of factors are not clearly recognized by the principal components method, it is necessary to transform them ie. rotate factors to achive factor independence. There are different ways of rotation, and the basic division is into orthogonal ("quartimax, varimax, equimax") and oblique, depending on whether the factors are uncorrelated (orthogonal) or correlated (oblique) (Cattell, 2012; Kline, 2014).

The factor loading represents the correlation of the factor describing it, so that a higher factor load means that the factor better describes the construct. For the sample size in this study (51), a factor level of 0.70 is considered significant for test strength 0.80 and a significance level of 0.05 assuming that the errors assume twice the value of the conventional correlation coefficient (Hair et al., 1998; Joseph et al., 2010).

Table 3. Factor loadings

Factor loading (Varimax raw) Method: Principal components (Significant loads >.7)		
	Factor - 1	Factor - 2
10.1	**0.908204**	0.374172
10.2	**0.964765**	0.171371
10.3	**0.859704**	0.289482
10.4	0.636330	**0.727179**
10.5	**0.872064**	0.130890
10.6	0.111489	**0.840722**
10.7	0.305721	**0.886343**
10.8	**0.861332**	0.421805
Explained variance	4.507897	2.469431
Share in total variance	0.563487	0.308679

The Cronbach α coefficient describes the degree of consistency between multiple measurements of a variable by a coefficient and is calculated according to the formula (Hair et al, 1998):

$$\alpha = \left(\frac{k}{k-1}\right) \cdot \left[1 - \sum \frac{{s_i}^2}{{s_{sum}}^2}\right], \quad (1)$$

where is:

${s_i}^2$- variance for k individual measurements,

${s_{sum}}^2$- variance for the sumo f all measurements.

The lower limit of acceptability for the Cronbach α coefficient is 0.70 as suggested by Nunnally, although many authors use less that 0.60, and the standardized α coefficient represents reliability when the values for all dimensions are standardized (z transformed), and calculated according to the formula (Hair et al., 1998):

$$\alpha_{st} = \frac{k \cdot \bar{r}}{1 + (k-1) \cdot \bar{r}} \quad (2)$$

where is:

k – number of dimensions in the scale,

$\bar{r}$ - mean correlation between dimensions.

The results of the reliability analysis are shown in Table 4.

Table 4. Reability of the scale - Cronbach α

Mean value=19.7059 Std.Dv.=15.7560 N:51 Cronbach α: .889347 Standardized α: .940875 Average correlation: .726901					
	Mean value – after rejection	Variance – after rejection	Standard Deviation– after rejection	Correlation	α - after rejection
10.1	18.23529	154.3368	12.42324	0.958385	0.840187
10.2	19.19608	212.4321	14.57505	0.903735	0.877141
10.3	11.80392	142.4713	11.93614	0.832600	0.868521
10.4	18.31373	144.2153	12.00897	0.842688	0.864456
10.5	14.54902	192.6005	13.87806	0.752565	0.868946
10.6	17.00000	226.5098	15.05024	0.469243	0.894917
10.7	19.58824	230.9481	15.19698	0.683474	0.895653
10.8	19.25490	210.7782	14.51820	0.943090	0.875073

Analysis in Table 4 shows that there is an adequate reliability of the scale, greater than 0.70.

5. CONCLUSIONS AND FUTURE AVENUES FOR RESEARCH

In this paper, statistical analysis of data obtained by surveying 51 companies in the Republic of Serbia that use certain type of crane transport system is done. The response to the conducted survey of 85% is a clean indicator of awareness of the problem of accidents that occur when using the crane transport systems.

The factor with the highest mean value, and even the best practice in Republic of Serbia, is the record of accidents/incidents in which the following data are: date of the incident, date of the beginning of incident investigation, description of the incident, identified causes of the incident, evaluation of potential hazards and probabilities, frequency of occurrence and recommendations needed to prevent the incident. The lowest value factor is related to the forwarding of incident reports of a certain crane transport system to other organizational units that use the same or a similar crane transport system. Reliability analysis also showed that there is adequate reliability of scale of all factors, while factor analysis showed a division into two groups of factors. The first group of factors consists of variables related to accident investigation procedures and records and the involvement of adequate staff in those jobs, and the second variables on failure history and incident/accident investigation reports. In this way, the redundancy of the data obtained by surveying the company was reduced, so that the conclusions can be reliable and valid.

The recommendation to companies in which crane transport systems operate is to:

- use the proposed measuring instrument to assess and monitor the situation, as valid and reliable,
- pay special attention to forwarding reports on incidents of the crane transport system to other organizational units in the company that use the same or a similar crane transport system,
- follow the procedures for investigating the causes of incidents/accidents, that the testing team includes a member trained in incident investigation techniques and a member thoroughly acquainted with the process of operation of the crane

transport system, that the record contains all necessary data, that based on failure history procedures for testing incidents of crane transport system, that adequate staff (engineers, crane operators…) are involved in the analysis of incidents/accidents ,that all reports on incidents/accidents are submitted to suppliers of crane transport systems and weather there is a written procedure the suppliers undertake to prove that the incident did not occur through their fault, that all reports on incidents of one crane transport system in the last year have been forwarded to all other organizational units using the same or similar crane transport system and that the incident investigation procedure necessarily requires that its findings be included in future risk analyses,

- when they exist, the shortcomings of their work should be balanced between two groups of factors – those related to accident investigation procedures and records and the involvement of adequate staff in these tasks, on the one hand and those related to failure history variables and incident/accident investigation reports on the other hand.

The proposal of further research is to link the obtained data with other variables that affect the operation of the crane transport system, such as the commitment of management to risk management, training of maintainers and operators, prescribed work procedures, process safety information, change management, occupational safety and machine inspection procedures.

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