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CRANE OPERATORS` ANTHROPOMEASURES FACTORS IDENTIFICATION

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Purpose of this paper is application of method based on multivariate statistical technique in order to determine critical dimensions of the crane cabin, which would maximize adjustability and ergonomics of the product, resulting in accommodation of wider range of the population and greater safety while operating. Multivariate statistical technique used for this purpose is factor analysis. Results of this research, conducted on a sample consisted of 83 crane cabin operators, showed that while designing a working space critical anthropomeasures take three-dimensional space, while theirinfluence contributions in each dimension are determined with factor analysis. Results of this work are expected to be useful for industry in a way such that crane cabins' designers can troubleshoot the dilemmas they encounter in their job. Using findings of this survey might lead to new designs of cabins that will offer less strenuous postures of operator, which consequently will improve productivity and safety.

Key words: Crane operator, Anthropomeasure, Factor analysis

INTRODUCTION

Taking into account that people have different heights, weights, that their extremities are of different lengths and more over that there are differences in age, education, gender, physical readiness, etc. one may say that seemingly two similar users can interact with product in completely different ways.

Working posture is believed to be influenced by manyfactors including workstation layout, location and orientationof work, individual work methods, and the workers'anthropometric characteristics (Hsiao&Keyserling, 1990). Hence, to design high quality product, in this case crane cabin, all of these variations must be taken into account and in such a way that will minimize production and designing costs. Since variations are explained with a lot more than just two variables, it is not suitable to use univariate and bivariate methods for their interpretation (Zehner, Meindl, & Hudson, 1993). In such cases, to obtain precise and adequate results multivariate analysis is required.

In that sense, if the design of the crane cabin is poorly fitted to the size and dimensions of the operator, the cargo may be less visible, indicators and regulators may be more difficult to see or reach, seat may be less comfortable, etc. As a result of inadequately designed cabins, from anthropometric point of view, as well as exposure to multiple stresses, operators are forced to work more carefully, in order to perform the task properly. Consequently, operators perform their job slower, rarely making brakes they usually need, and such physical exertion has a negative effect on the overall state of fatigue, including mental fatigue, which reduces the perception abilities of workers.

Therefore, the purpose of this paper is to develop safe and ergonomically adjusted crane cabin through factor analysis application.

PREVIOUS RESEARCH

In recent years, traditional percentile approach has been criticized for the decrease in accommodation when two or more dimensions are in-

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volved in a design, so today there is a tendency of using multivariate approaches in cases involving such problem (Bittner 1987, Gordone at al., 1997; Zehner, Meindl, & Hudson, 1993).

Data collected on crane operation rarely appear in literature. Collections of operators` needs data was conducted through apllication of control lists proposed by Kittusamy (2003) and similar survey was done in Nordin and Ollson (2008) for leading manufacturers in Sweden. Also, on a sample consisting of 46 crane operators Bovenzi, Pinto &Stacchini (2002) found 40-60% with 12-month prevalence of low back pain. Data on crane anthropomeasures even rarely appear, solely Ray and Tavari (2012) studied 23 body dimensions of 21 crane operators to minimize the anthropometric mismatch within the enclosed workspace and found many misfits of even the 50th percentile crane operator.

Previous research, although not extensive, points out the need to increase the well-being of crane operators and facilitate the operator-cabin interaction, so discomfort and accidents at work would be avoided, through anthropometric characteristics analysis. In that way safety would improve and crane related fatalities and injuries prevented. Dondur et al. (2012) have proved that it is economically feasible to produce and use the new generation of crane cabins with considerably lighter weight and stiff structure, whose interior space is optimized, and proposed that all crane cabins should be developed by using the methods of physical, cognitive and organizational ergonomics.

MATERIAL AND METHODS

Sample

The share of crane operators in any general population is quite low. Hence, we surveyed Serbian crane operators and our sample comprised 83 participants. All participants were male, with an average age of 47.64, with standard deviation of 10.34 years. Measurements were taken in several plants located throughout Serbia, where a large number of cranes are stationed. The sample was formed by means of the static anthropometry method. A total of 9 basic static anthropometric dimensions, including weight, were recorded for each individual, namely 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). The standard anthropometric instruments used in this study were an anthropometer, 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.

Factor analysis

Factor analysis is based on interrelation of observed variables which is expressed with correlation coefficient and aims to express variables through determined space baseof the observed variables (Hair, 2011). With factor analysis observed variables are expressed with smaller number of variables which are called factors. It is important to notice that these factors are linear independent, that is, none of the factors can be expressed as combination of the remaining factors, while combination of these factors can give all observed variables. Main task of factor analysis is therefore to determine smaller number of the factors, compared to the number of the variables, and afterwards to determine relationship between variables and factors.

As indicated, the aim of factor analysisis to reduce "the dimensionality" of the original space and express observed variables through factors. Variables can be presented as linear combination of factors (Gorush, 1997).

Let Z_j , Xg and Si be random values with following characteristics:

Z_j is a variable such that:

$M(Z_j) = 0$ and $M(Z^2_j)=1$, j=1,2...n.

Xgis commonfactor such that:

$M(X_g) = 0$ and $M(X^2_g)=1$, g=1,2...r, r n.

Si is unique factor such that:

$M(S_i) = 0$ and $M(S^2_i)=1$, i=1,2...n.

According to the factor characteristics following applies:

$COV\ (X_g, S_i) = 0$ (g=1,2...r i=1,2...n)

$COV\ (X_a, X_b) = 0$ (a b)

$COV\ (S_a, S_b) = 0$ (a b)

Supposing Z is a random factor with dimension nx1 which random variables' components are X_1, X_2 ...X_n, Z can be described as complex variable or standardize variable, expressed in the function of common and unique factors, which has following form:

$$Z_j = \sum_{i=1}^{r} f_{ji} X_i + u_j S_j \qquad (1)$$

Equation above is called fundamental factor equation, where f_{ji} denotes factor loading and uj denotes standardized coefficient of the variable and unique factor. It can be noted that all of the variables contained in Z represent complex variables composed of weighted combinations of common and unique factors.

RESULTS

The most adequate way to organize data for factor analysis, as adopted multivariate analysis, is matrix. In this paper that matrix consists of rows which represent crane cabin operators and there are 83 of them, and columns which represent 8 variables describing them. Table 1 shows descriptive statistics of the input data, and tables 2-4 including figure 1 are showing results of the factor analysis application.

Factor analysis starts with correlation coefficients which measure the extent to which variables are related. Interrelation among variables comes fromthe affect of common factors on all variables and therefore correlation coefficients can be expressed particularlythrough those factors. Researcher also must assure that data matrix has enough correlations, as this is required by factor analysis. Visual inspection should reveal substantial number of correlations greater then 0.30 (Gorsuch, 1997). Correlation matrix of the variables used in this paper is given in table 2. Inspection of this table shows that there are enough correlation coefficients greater then 0.30, so application of factor analysis is recommended.

Since correlation coefficients depend on the number of data, it is necessary to conduct factor analysis on such a number of data that guarantee stability of the correlation coefficients. If number of the variables is under 8, sample must comprise at least 32 subjects, and for a larger number of variables, number of subjects must be 3 to 5 times greater then number of variables. To analyze crane operators anthropomeasures 8 variables are used and 83 subject investigated, which adds up to ratio of 10.3.

Typical factor analysis is implemented in following couple of steps. First step is to calculate all correlation coefficients among variables (table 2). Second step is calculation of the eigenvalues and factor loadings, using correlation matrix (table 3). Next is making the decision about how many factors should be retained. For this purpose diagram shown in figure 1 is constructed. Diagram is derived by plotting the latent roots against the number of factors in their order of extraction, and the shape of the resulting curve is used to evaluate the cutoff point. Latent root or eigenvalue is sum of squared factor loadings from a column and represents amount of variance explained with a factor. As can be seen in figure 1 the point corresponding to the third component is the point at which the curve first begins to straighten out, and since this is consider to indicate the maximum number of factors to retain, herein three factors, explaining 80.77% of variance, have been retained. Last step of the analysis includes interpretating and naming the common factors.

Factor matrix have the characteristics of simple structure. That can be seen while inspecting loading matrix, as each row only has very high or very low loadings. If loadings that are lesser then 0.7 are consider to be small and insignificant, then loading matrix is left with only significant loadings which can be used for interpretation of the factors.

Table1: Descriptive statistics of the input data

Measurement	Shoe number	Height (mm)	Sitting height (mm)	Lower leg height (mm)	Upper leg length (mm)	Shoulder width (mm)	Hip width (mm)	Arms length (mm)
Mean	43.34	1768.19	907.31	587.17	618.23	478.35	399.39	704.55
Standard Deviation	2.026	68.210	56.749	40.176	36.350	48.520	53.326	50.892
Minimum value	40	1630	750	490	520	380	300	495
Maximum value	48	1937	1020	770	710	580	580	800

Zero or negligible factor loadings are distributed according to requirements of simple structure, that is they are placed in the certain rows as well as in the certain columns of the matrix. Presence of zero factor loadings in the certain rows means that factor complexity of certain observed variables is reduced. This means that every variable has meaningful loadings on just one factor, i.e. it can be identified with only one factor. Zero or negligible factor loadings in certain columns mean that certain factors differ from one another (Milanović, 2008).

Table 2: Correlation matrix

	Correlations N=83							
	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8
Var1	1.00	0.56	0.49	0.45	0.30	0.34	0.30	0.50
Var2	0.56	1.00	0.75	0.43	0.34	0.19	0.09	0.61
Var3	0.49	0.75	1.00	0.31	0.27	0.09	-0.13	0.64
Var4	0.45	0.43	0.31	1.00	0.49	0.45	0.45	0.57
Var5	0.30	0.34	0.27	0.49	1.00	0.45	0.40	0.41
Var6	0.34	0.19	0.09	0.45	0.45	1.00	0.76	0.34
Var7	0.30	0.09	-0.13	0.45	0.40	0.76	1.00	0.09
Var8	0.50	0.61	0.64	0.57	0.41	0.34	0.09	1.00

Table 3: Factor loadings matrix

	Factor Loadings			Extraction: Principal components				
	Factor	Factor	Factor	Factor	Factor	Factor	Factor	Factor
Var1	-0.729888	0.122979	-0.488177	-0.035480	0.382441	-0.255199	-0.014302	0.031173
Var2	-0.754256	0.448813	-0.096961	-0.162361	-0.021632	0.355498	0.237352	0.103535
Var3	-0.659740	0.625992	-0.016873	-0.168463	-0.168436	0.075491	-0.314002	-0.107451
Var4	-0.761157	-0.183398	0.173529	0.528381	0.154789	0.184456	-0.120761	0.071693
Var5	-0.652254	-0.257244	0.568791	-0.335633	0.252839	-0.090806	0.003271	0.005705
Var6	-0.616581	-0.631720	-0.130911	-0.119560	-0.358407	-0.106586	-0.073413	0.210046
Var7	-0.483016	-0.786417	-0.209719	-0.063844	-0.015353	0.183435	0.042125	-0.254023
Var8	-0.794059	0.296537	0.150511	0.227683	-0.259466	-0.296864	0.193029	-0.119713
Expl.Var	3.785695	1.813689	0.685413	0.518046	0.459001	0.372611	0.214156	0.151388
Prp.Totl	0.473212	0.226711	0.085677	0.064756	0.057375	0.046576	0.026770	0.018923

Table 4: Eigenvalues of the correlation matrix and values of the total and cumulative variance

	Eigenvalues Extraction: Principal components			
	Eigenvalue	% Total	Cumulative	Cumulative
1	3.785695	47.32119	3.785695	47.3212
2	1.813689	22.67112	5.599385	69.9923
3	0.685413	8.56766	6.284798	78.5600
4	0.518046	6.47558	6.802844	85.0355
5	0.459001	5.73752	7.261845	90.7731
6	0.372611	4.65764	7.634456	95.4307
7	0.214156	2.67695	7.848612	98.1077
8	0.151388	1.89235	8.000000	100.0000

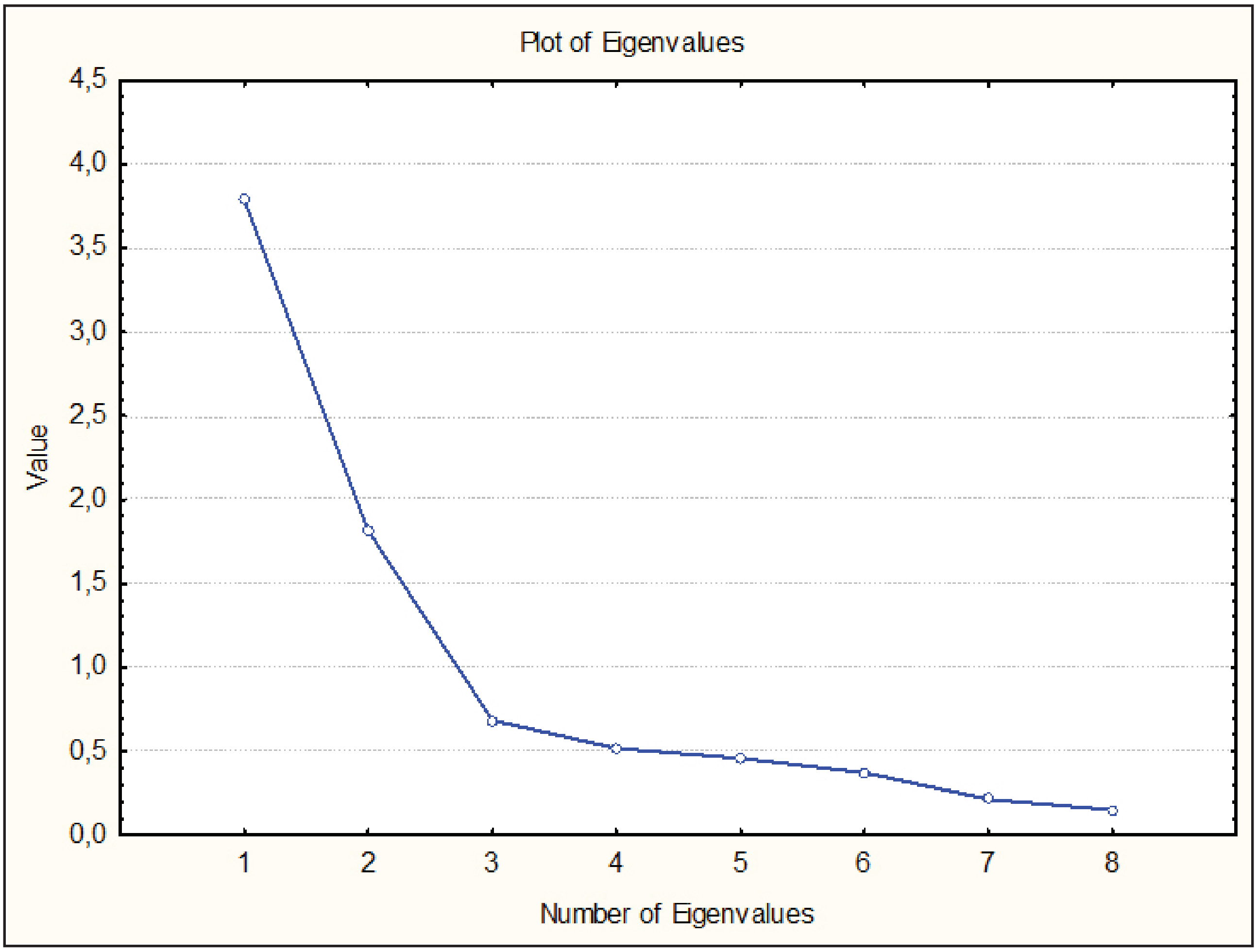

Figure 1: Diagram representing eigenvalues

DISCUSSION

When analyzing results derived from factor analysis of the crane operators anthropomeasures data one can conclude that three factors stand out with substantial factor loadings, namely:

- Height of the crane operator's workplace,
- Width of the crane operator's workplace,
- Depth of the crane operator's workplace.

Factor "Height of the crane operator's workplace" is the main factor and the most important one, since it explains the most of common variation of the variables. Considering structure of the variables which form this factor it can be noticed that factor is very homogeneous. All of the variables have significance factor loading greater then 0.7, so it is difficult to single out the most influential variable. Variables forming this factor are:

- Var2 "Height in mm" with factor loading 0.747642.
- Var4 "Lower leg height in mm" with factor loading 0.792885.
- Var5 "Upperleg length in mm" with factor loading 0.753270.
- Var8 "Arm length in mm" with factor loading 0.742173.

Common characteristic of all of these variables is that they all refer to height.

Second factor, called "Width of the crane operator's workplace" is composed from fallowing variables:

- Var6 "Shoulder width in mm" with factor loading 0.802091.
- Var7 "Hip width in mm" with factor loading 0.913037.

Variables forming this factor refer to width. They are homogeneous with high significance factor loadings.

Third factor is interpreted as "Depth of the crane operator's workplace" and it is composed of a single variable:

- Var1 "Shoe number" with factor loading 0.789659.

Analysis of the factors leads to certain conclusions about observed phenomenon. In this case findings are that three factor are formed, interpreted as height, weight and depth, which is in compliance with logic reasoning that for designing of working space in the crane cabin the most important operator's anthropomeasures are describing three-dimensional space.

Application of factor analysis and identification of factors provide posibbility of predicting changes that will occur in one variable by knowing and measuring changes in some other variable. Factors determined during factor analysis have fundamental meaning relative to the observed variables. Thus, newly formed factors, which explain crane operators' anthropomeasures, in a large part have the same characteristics as do important infuential factors determined in research so far. Results of factor analysis indicate the significance of the main crane operators' athropomeasures and provide framework for design of the workplace. Significance of this research lies in a fact that crane cabin designed accoring to these results will be adjuted to operator, that is it would provide humanised working in this system which would offer less strenuous postures of operator, consequentlyleading to improvement of theproductivity and safety.

CONCLUSION

Further research should seek to determine in what extent do identified factors satisfy dinamic analysis. Workplace in the crane cabin should be adjusted to worker, so productivity as well as safety would be increased. The overall approach regarding this issue is much more complexed, if funcioning of the system is taken into account, and requires application of complex workplace optimization method. The basis of that method are identified factors of the crane operators' anthropomeasures determined in this paper.

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