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ERGONOMIC APPROACH TO WORKPLACE (RE)DESIGN DURING LOADS HANDLING

Abstract: *Manual handling of loads is a set of activities that involve physical strain during work. For this reason, it is necessary to create ergonomically sound workplaces, which will help improve health and safety in the workplace. The paper describes an approach, which includes ergonomic and productivity factors, for choosing the optimal alternative for loads handling using multicriteria analysis. The purpose of this approach is to select the most important criteria to make decisions on how to reorganize the work process, as well as to meet ergonomic performance goals, all with minimal impact on the company's productivity. The objective of this paper is to analyse and select the optimal alternative for manual handling of loads using the Analytic Hierarchy Process method. The results of the research revealed that handling loads is a more optimal solution when performed by a single person, taking into account ergonomics and productivity aspects, compared to working in pairs or using conveying systems as transport aids.*

Keywords: ergonomics, productivity, AHP method, manual handling of loads, occupational safety and health.

INTRODUCTION

Ergonomics, as a multidisciplinary science, integrates knowledge and skills from various scientific fields (engineering, technology, philosophy, medicine, psychology, design, etc.) in a comprehensive manner. There is no single definition of ergonomics as a science, yet, in diverse areas, it is defined differently. The International Ergonomics Association (IEA) has provided a comprehensive definition of ergonomics as a scientific discipline concerned with the understanding of interactions among workers and other elements of the work environment, and the profession that applies theory, principles, data, and design methods in order to optimize human well-being and overall system performance [5]. Such a definition of ergonomics fully corresponds to the field of occupational safety engineering; it takes into account the impact of all elements of a system on man and his psychophysical abilities, limitations, and similar. The practice has shown that the application of ergonomic principles is most often aimed to satisfy legal requirements, on the one hand, i.e. to reveal the results pertaining to occupational safety on the other hand. This approach disregards the financial results of a company, which makes the application of ergonomic principles unacceptable. Therefore, all problems from an ergonomics perspective must be viewed in parallel with the company's business performance [17].

Rapid technical and technological development emphasizes the automation and mechanization of the system, thus neglecting the activities of workers who have to keep pace with modern technological system [8]. Therefore, the paper deals with one of the issues which appear in various systems as an integral part of all activities - manual handling of loads.

According to the national legislation of the Republic of Serbia, manual handling of loads means any transporting or supporting of a load weighing more than three kilograms, by one or more workers, including lifting, putting down, pushing, pulling, carrying, or moving of a load, which, due to its characteristics or unfavorable ergonomic conditions, particularly involves a risk of injuries or spinal disease to workers [12].

The objectives of this paper are to analyze and select the optimal alternative for manual handling of loads using a multi-criteria approach based on the Analytic Hierarchy Process (AHP) method.

On account of the identified problem and defined goals, the research covers the following tasks:

- Defining criteria that can have an impact on ergonomics workplace conditions and productivity at work;
- Structuring the problem in relation to the defined criteria and alternative solutions being considered;
- Data processing and drawing conclusions about the most acceptable solution.

LITERATURE REVIEW

By literature analysis, we can conclude that a large number of researchers worldwide deal with the issue of manual handling of loads and its consequences on the workers' safety and health and productivity at work. Shikdar et al. (2011) point out that improving worker productivity is a major problem in the industry, especially where tasks involve repetitive movements. These tasks are considered boring, monotonous, tedious and demotivating, and they result in reduced workers' productivity, poor job quality and habitual absence from work, which may have adverse effects on the psychophysical condition of workers. They also believe that the effective use of ergonomic principles in workplace design can help in creating a balance between employee characteristics and job requirements [16].

Otto and School (2011) point out that nowadays, in assembly-line production, where the share of manual labor is high, special attention is paid to ergonomics. They also believe that factors such as posture, force, repetitive movements and vibrations, which result in a higher injury rate, should be strictly considered when (re)designing the workplace and work environment [11].

Muhundhan (2013) emphasizes that the workplace must be designed by considering ergonomic principles in order to work efficiently, make high-quality products, and increase productivity. He also points out that a well-organized workplace minimizes material handling, improves efficiency and reduces worker fatigue, and that the implementation of appropriate work organization can improve productivity and efficiency of workers in terms of quality and quantity [9] On the other hand, Gurunath et al. (2012) believe that instead of investing money in materials, man, machines, working methods, etc., manufacturers should invest in providing an ergonomic workplace because it is cost-saving [4]. An ergonomically designed workplace in industries with proper modular structure provides many benefits, such as increased motivation and employee satisfaction, higher performance and processing quality, and the like [7].

According to Osabiya (2015), workers who are dissatisfied with workplace conditions are less productive regardless of their potentials. This dissatisfaction may jeopardize workplace peace and create increasing disequilibrium between the efforts made by the employees and the productivity achieved [10].

METHODOLOGY

The *Analytic Hierarchy Process* (AHP), developed in 1980 by T. L. Saaty [15], is a method of multi-criteria decision making that includes both qualitative and quantitative techniques, which reflects its usefulness for obtaining a unique assessment based on given criteria. It proposes the most acceptable solution from a set of defined criteria and attribute values for each alternative [2]. As such, this method simplifies the decision-making process by decomposing a complex problem into a series of structured steps, where each element in the hierarchy of criteria is independent of all the others, and where the analytical network process is used to denote the interdependence of criteria [1].

The AHP method is based on the comparison of pairs, according to criteria that differ in importance, it is mathematically well-defined and very close to the way an individual intuitively solves complex problems by breaking them down into simpler ones [13] and consists of 3 phases (steps):

The first step is decomposition, within which the hierarchical structure of elements that influence decision-making is made in such a way that the goal is set at the top; the next level (below) is the position at which the criteria are placed, while the alternatives are placed at the bottom. In this procedure, elements of a general character are placed at a higher level of the hierarchy, while those of a specific character are placed at lower levels of the hierarchy. The decision-maker can insert or delete individual elements in order to clarify the task of setting priorities.

The second phase is the pair-wise comparison, where a database comparing the set of alternatives to a reference alternative is made. Pairwise comparisons are done based on Saaty's Scale of Importance [14], by assigning values from the set {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9}, where on the scale, 1 means that both factors (which we compare) are of equal importance, whereas 9 indicates that the first factor in the pair is more important than the other factor.

After pair-wise comparison, the decision-maker calculates their relative weights in relation to the goal; then compares the alternatives (in pairs) in relation to each criterion and assigns relative weights, thus creating the above-mentioned database on compared pairs. Mathematically, it is a matter of calculating characteristic roots and characteristic vectors.

The third phase is the synthesis of priorities, within which the vector of the relative weight of decision alternatives and the vector of the order of activities related to the criteria within the model are obtained. Based on that, the order of importance is calculated for each of the decision alternatives, for each observed criterion. Finally, the rate of each alternative is multiplied by the weight of the observed criterion, then these values are added for each alternative separately, and in the end, the weight of the observed alternative in the model is obtained (similar to all alternatives) [2]. In the end, the final order of alternatives in the model is determined and the most suitable option is selected according to the chosen criteria.

In particular, to check the subjectivity of decision making, the consistency of the model is monitored by calculating the ratio of consistency index (*CI*) and consistency ratio (*CR*), which represents the ratio of consistency index and random consistency index (*RI*):

CR=CI/RI

where *CI=(λ_max-n)/(n-1)*, *n* is the order of the observed matrix, while *λ_max* is the maximum characteristic root of the observed matrix. The value of the random consistency index (RI) is denoted by the order *n* of the matrix of randomly generated pair comparisons. In that way, in the case of the first 15 numbers, the table of values of the random consistency index has the following form [15]:

Table 1. *The table of values of the random consistency index*

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,48	1,56	1,57	1,59

Otherwise, it is necessary to find the reasons for high inconsistency in the assessment [16]. A detailed explanation of the method is presented in the works of Saaty (1980), Inđić, et al. (2014) [15, 6].

RESULTS AND DISCUSSION

For the purpose of multi-criteria analysis in which AHP is applied, we can define the following goal: to organize the workstation during the handling of loads. In the first phase of application of the AHP method – decomposition - the authors set a goal and defined three alternatives to the process of organizing the workstation during handling of loads:

1. loads handling when stacking goods performed by a single person (A1),
2. loads handling when stacking goods performed in pairs (A2),
3. the use of conveyor during stacking (A3).

While choosing and formulating the alternative, the authors tended towards generality, i.e. to adjust the structure of the alternatives so that they can be applied to several different types of load handling activities in different companies.

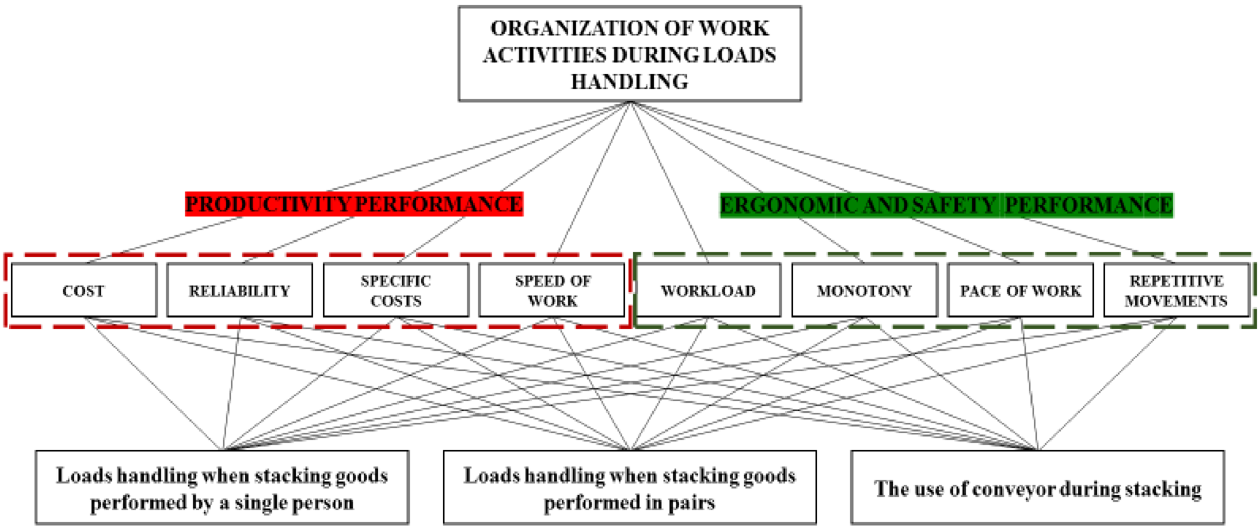

Figure 1. *The structure of workplace organization during loads handling*

According to the AHP structure, the next level in the hierarchy is the criteria. Based on a theoretical example from practice, the study identified indicators of productivity and ergonomics which are dominant in defining the criteria. Also, in order to emphasize the criteria according to importance, a grouping of smaller sub-criteria was performed in eight units divided into two groups. The first group of indicators refers to productivity and includes four criteria: cost, reliability, specific costs and speed of work. The second group of indicators refers to the ergonomics of work when handling loads, which also includes four criteria: workload, monotony, the pace of work and repetition of movements (see Figure 1). For the selection of the most suitable ergonomic solution for the organization of work in loads handling, the above criteria are described in Table 2.

Table 2. *Categorization of decision criteria*

Number of criteria	Decision criterion	Description of criteria
C1	Cost	It implies the necessary financial resources needed to organize work in case of all the above methods
C2	Reliability	It implies the reliability of performing load handling activities
C3	Specific costs	They include regular or unplanned downtime costs (maintenance, servicing, replacement of spare parts, resources, etc.)
C4	Speed of work	It implies the pace of work with regard to the speed and efficiency of the operation
C5	Workload	It involves the physical load of workers when handling loads
C6	Monotony	It involves repetitive movements and the social environment
C7	Pace of work	It implies dictated work pace
C8	Repetitive movements	It implies the required degree of repetitive movements in a unit of time

The second phase involved assigning importance to the attributes based on the pairwise comparison and creating a database on the pairwise comparison between given alternatives with regards to the given criterion. First, a pairwise comparison matrix for the criteria was created, in which each criteria pair was assigned the appropriate values according to the Saaty's scale, in the 1–9 range (see Table 3).

Table 3. *Matrix of pairwise comparison of criteria at the first level (decision matrix)*

	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	1/6	1/5	1/3	1/5	1/5	1/3	1/4
C2	6	1	3	4	1	2	1/3	2
C3	5	1/3	1	2	3	4	4	3
C4	3	1/4	1/2	1	3	4	1	1
C5	5	1	1/3	1/3	1	1	2	1/3
C6	5	1/2	1/4	1/4	1	1	1/2	1/3
C7	3	3	1/4	1	1/2	2	1	1/2
C8	4	1/2	1/3	1	3	3	2	1
∑	**32**	**6,75**	**5,867**	**9,917**	**12,7**	**17,2**	**11,167**	**8,417**

According to the AHP procedure, the upper matrix was normalized and the relative weights were calculated. Using Saaty's measurement scale, by comparing pairs of alternatives, the weights of the relative importance of alternatives were assigned to the observed criterion C1-C8 (see Tables 4-11, respectively).

The assessment obtained in this way represents the average preference of one alternative with regards to others, i.e. the value of the weight needed to make the final decision [18]. With this approach, we get more precise solutions, when it comes to pairwise comparisons, as well as steady solutions which make us assume that a small change in values will not cause large changes in the final assessment [18].

Table 4. *Matrix of alternative relative importance compared to the cost (C1 attribute)*

	A1	A2	A3
A1	1	4	8
A2	1/4	1	4
A3	1/8	1/4	1

λ	**3,0536**
CI	**0,0268**
CR	**0,0462**
CR<0.1	**YES**

Table 5. *Matrix of alternative relative importance compared to reliability (C2 attribute)*

	A1	A2	A3		
A1	1	5	9	**λ**	**3,0712**
A2	1/5	1	4	**CI**	**0,0356**
A3	1/9	1/4	1	**CR**	**0,0614**
				CR<0.1	**YES**

Table 6. *Matrix of alternative relative importance compared to specific costs (C3 attribute)*

	A1	A2	A3		
A1	1	3	7	**λ**	**3,065**
A2	1/3	1	5	**CI**	**0,0325**
A3	1/7	1/5	1	**CR**	**0,056**
				CR<0.1	**YES**

Table 7. *Matrix of alternative relative importance compared to the speed of work (C4 attribute)*

	A1	A2	A3		
A1	1	1/3	1/9	**λ**	**3,029**
A2	3	1	1/5	**CI**	**0,0145**
A3	9	5	1	**CR**	**0,025**
				CR<0.1	**YES**

Table 8. *Matrix of alternative relative importance compared to workload (C5 attribute)*

	A1	A2	A3		
A1	1	1/4	1/9	**λ**	**3,0369**
A2	4	1	1/4	**CI**	**0,01845**
A3	9	4	1	**CR**	**0,0318**
				CR<0.1	**YES**

Table 9. *Matrix of alternative relative importance compared to monotony (C6 attribute)*

	A1	A2	A3		
A1	1	1/3	2	**λ**	**3,0037**
A2	3	1	5	**CI**	**0,00185**
A3	1/2	1/5	1	**CR**	**0,0032**
				CR<0.1	**YES**

Table 10. *Matrix of alternative relative importance compared to the pace of work (C7 attribute)*

	A1	A2	A3		
A1	1	3	6	**λ**	**3,019**
A2	1/3	1	3	**CI**	**0,0095**
A3	1/6	1/3	1	**CR**	**0,0164**
				CR<0.1	**YES**

Table 11. *Matrix of alternative relative importance compared to repetitive movements (C8 attribute)*

	A1	A2	A3		
A1	1	3	7	**λ**	**3,0327**
A2	1/3	1	4	**CI**	**0,01635**
A3	1/7	1/4	1	**CR**	**0,0282**
				CR<0.1	**YES**

The verification of the subjectivity of decision making was followed by calculating the values of consistency index (CI) and consistency ratio (CR) which were less than 0.1 in the case of these matrices (see Tables 4-11, right column, respectively); therefore, the relative importance criteria were considered acceptable.

Table 12. *Optimal alternative selection table*

	w	A1	w×A1	A2	w×A2	A3	w×A3
C1	0,026	2,267	0,059	0,733	0,019	0,233	0,006
C2	0,214	0,187	0,040	0,709	0,152	2,104	0,450
C3	0,220	1,93	0,425	0,849	0,187	0,221	0,049
C4	0,124	1,959	0,243	0,753	0,093	0,288	0,036
C5	0,094	0,201	0,019	0,660	0,062	2,139	0,201
C6	0,065	0,689	0,045	1,944	0,126	0,367	0,024
C7	0,123	1,959	0,241	0,753	0,093	0,288	0,035
C8	0,133	1,967	0,262	0,794	0,106	0,239	0,032
			1,334		0,838		0,833
		LEVEL	**1**		**2**		**3**

By calculating the relative weights concerning each criterion, an optimal alternative is selected. The calculated weight vector of criterion *w* (see Table 12, column *w*), indicates that the criterion “specific costs” (C3) has the greatest significance (0.220) compared to other criteria. In addition to the above, the criterion “reliability” (C2) with a specific weight of 0.214 stands out, which indicates the influence of the productivity criterion on the final decision.

The optimal alternative was chosen by multiplying all relative weights of the alternatives (according to the appropriate criterion) by the weight vector *w*, and then by summing the corresponding results (see Table 11, last row). The alternative with the highest value (in this case A1) is the one that is considered optimal. Based on the obtained results, we can conclude that independent handling of loads when stacking goods by a single person is an optimal alternative for handling loads with a mass that does not exceed the prescribed maximum allowed values. Also, the research results show that people are most aware of their capabilities and limitations at the moments when they should take a break or stop working, and realize the pace of work that suits them best, etc. On the other hand, the specific costs that appear in the case of using a conveyor (A3) or other technical aid, are almost non-existent; however, these costs trigger many others, latent costs, which are mostly reflected in the loss of time and downtime due to various failures.

CONCLUSION

The paper presents the application of the multicriteria AHP method in the process of organizing work activities during the handling of loads, involving given criteria pertaining to productivity and ergonomics. Bearing in mind the fact that ergonomically (re)designed workplace greatly contributes to increasing workers’ health and safety in the workplace, while increasing their satisfaction with work conditions at the same time, which, in turn, affects their productivity, the authors considered both economic and productivity criteria in deciding how to organize the workstation during handling of loads. Therefore, the paper analyzes both aspects, with the aim to make balanced decisions about the reorganization of the work process, and simultaneously satisfy ergonomic performance with minimal impact on the company's productivity. At the same time, one of the main problems (in terms of subjectivity) was to determine the criteria related to productivity and ergonomics. The subjectivity of decision-making by the author is reflected in the decision-making criteria and the assessment of their relative weights. The authors defined the criteria and evaluated their relative weights based on the available literature and their personal experience. The assessments of the relative importance were confirmed by checking the consistency ratio.

By applying the AHP method in this research, it was assumed that the alternative "handling of loads by a single person" has the highest total value of 1,334, which means that it is the most favorable alternative when it comes to choosing the type of work organization in loads handling. Although the alternative A1 may be the most favorable solution, it must include a series of measures, such as the introduction of breaks during the work, proper lifting and transfer of loads in accordance with safety instructions and procedures, and the like.

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ERGONOMSKI PRISTUP (RE)DIZAJNIRANJA RADNOG MESTA PRI MANIPULACIJI TERETOM

Lutvo Haznadarević, Novak Milošević, Dragana Gardašević, Nebojša Ćurčić, Evica Stojiljković

Rezime: *Ručno prenošenje tereta predstavlja skup aktivnosti koje od čoveka zahtevaju različite vrste fizičkog naprezanja pri radu. Zbog toga je neophodno da radna mesta budu ergonomski prilagođena zaposlenima, čime se doprinosi povećanju njihove bezbednosti i zdravlja na radu. U radu je opisan pristup, koji obuhvata faktore ergonomije i produktivnosti, za izbor optimalne alternative pri manipulaciji teretom primenom višekriterijumske analize. Svrha ovog pristupa je izbor najvažnijeg kriterijuma prilikom donošenja odluke na koji način se proces rada može reorganizovati, a da se u najvećoj meri zadovolje ergonomske performanse, uz minimalna narušavanja produktivnosti kompanije. Cilj ovog rada je analiza i odabir optimalne alternative za ručno prenošenje tereta primenom metode „Analitički hijerarhijski proces". Rezultati sprovedenog istraživanja pokazali su da samostalno manipulisanje teretom predstavlja optimalnije rešenje, uzimajući u obzir aspekte ergonomije i produktivnosti, u odnosu na rad u paru ili upotrebu transportera kao pomagala.*

Ključne reči: ergonomija, produktivnost, AHP metoda, ručno manipulisanje teretom, bezbednost i zdravlje na radu.