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Selection of Personal Protective Equipment - a complex issue of multi-criteria analysis

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Abstract. It is known the fact that in both the Member States of the European Union and the United States, the provision of Personal Protective Equipment (PPE) to workers who are carrying out their activity in different sectors is done in accordance with existing legislation and regulations specific to each state. However, choosing a suitable PPE for a particular workplace is a difficult task to perform given that there are a variety of PPE on the market that perform, in different ways these functions: to prevent an accident - from the same place of work. to protect the health and safety of workers and to minimize damage from any possible accident. Comparing the alternatives, in order to find the most favourable protective equipment specific to a particular workplace, is a complex multi-criteria decision problem that sometimes is difficult to solve. In this paper we approached a method of multi-criteria analysis of the decision, respectively we applied a Analytical Hierarchy Process (AHP) to select PPE -favourable to a certain job: mechanical locksmith. Our work allowed us to find the dominant criteria and the critical factors in the products evaluation, multi-criteria evaluation AHP of employees' requirements, regarding PPE and ergonomic aspects.

1 Introduction

In the last period of time, the workers in safety and health at work have been more concerned with granting PPE, according to the existing legislation and regulations so as to ensure a safe workplace, [1, 2]. The multitude of personal protective equipment currently on the market sometimes makes it impossible to make the optimal choice of work equipment suitable for a particular workplace so as that equipment to ensure maximum safety. It was considered that the selection of an individual work equipment is not a technical procedure, being rather a subjective and uncertain process, [3, 4]. It depends on the evaluation of the objectives, on the measurable criteria (ex: acquisition costs, maintenance costs, etc.) as well as on subjective criteria (compatibility, ergonomics, technical factors, etc.). The selection of an individual protective equipment is a multi-criteria decision problem that refers to the choice of an equipment to protect the employee's life, from a lot of products of the same type, based on their evaluations in relation to a lot of criteria.

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Complex problems of decision have the following characteristics that lead to the difficulty of solving them, [5,6]:

- the large number of real possible solutions, an aspect that makes it difficult to find the best solution
- the decision problem evolves in a time-dependent environment, namely the decision considered yesterday to be optimal today is no longer optimal;
- there are a multitude of criteria that must be taken into account in choosing the decision.
- difficulty in finding a reasonable solution capable of satisfying several restrictions imposed by laws, regulations, capacities, preferences, etc.

The studies carried out by Ozernoy, V. M. [7], showed that in obtaining of a good decision it matters both the choice of an adequate structuring of the decision problem and the choice of a solution method.

Often, solving of different decision problems requires the approaching of a Multi Criteria Decision Making method - (MCDM), [8, 9].

The purpose of our work is to choose the appropriate helmet for the mechanical locksmith in a machining unit, in accordance with current legislation, risk factors specified by prior risk analysis, ergonomics, employee comfort and economic aspect, so as to ensure maximum protection of the employee - having three types of helmets.

2 Materials and methods

Our problem of multicriteria decision is a matter of choice in which we look for the best variant of a safety helmet for industrial use adequate for a workplace, non-dominant of three alternatives {A_1, A_2, A_3} whose technical characteristics are presented in table 1. For ethical reasons, we did not present the name of the safety helmet for industrial use or the manufacturing company. In this sense, to solve this problem of multicriteria analysis we adopted a hierarchical method of solving, respectively the Analytical Hierarchy Process (AHP) method - considered to be a multi-attribute decision method with a unic criterion of synthetisation, [10].

Table 1. Characteristics of safety helmets for industrial use (from product data sheet).

Alternative	Characteristics								
	Price (€)	MC (€)	QM	Designe	Force [kN]	Mass [g]	IER [J]	LC [mA]	RT [^{0}C]
A_1: Safety helmet 1	45	24	Very high quality	Ergono-mics-special	3,6	360	30	1,2	-30
A_2: Safety helmet 2	33	-	High quality	Ergo-nomic	4,8	338	30	1,1	-40
A_3: Safety helmet 3	18	18	Quality	Adaptiv	4,1	255	30	0,8	-10
QM- Quality materials; MC- maintenance costs; IER-Impact energy resistance; LC -Leakage current at 1200V; RT - Resistant properties at temperatures up to.									

The AHP method was developed by Saaty [11] being an approach based on the decident preferences assessed on a scale of importance intensity of called the Saaty scale. The method is a compensatory method with a linear additive model, used in choice and ordering problems. An extension of this method is "Analytic Network Process" (ANP), [12, 13].

For solving the problem, we chose the decisional hierarchy presented in figure 1 which has 3 levels. The highest level is the general decision, the middle level describes the decision criteria or decision factors, that will be considered in choosing of the best helmet and the lower level represents the three types of alternative helmets compared

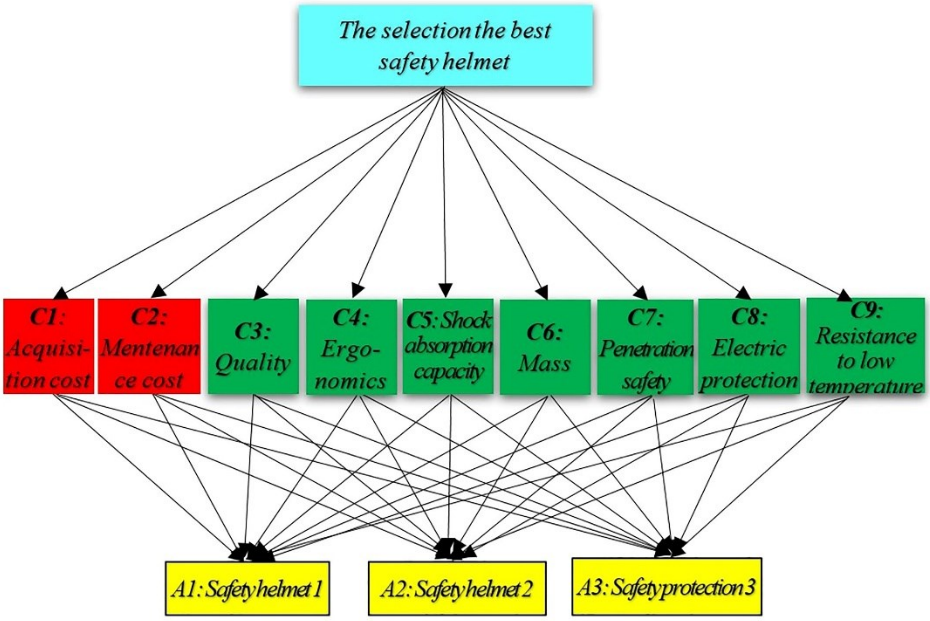

Fig. 1. Decisional hierarchy: Level I – Ojective; Level II – Decision criteria or decision factors; Level III - Alternative.

It is observed that C_1 and C_2 are economic criteria and the criteria C_3- C_9 are criteria related to worker safety.

The solving of the problem, respectively the establishing the best safety helmet have presumed the comparing, in pairs, two by two of each safety helmet in relation to each established criterion (C_1-C_9), the comparing of the criteria between them and scoring with the ratings from the comparison scale of the Saaty preferences - table 2.

Table 2. Preferences comparison scale (Saaty)

If the contribution of the alternative A_i in relation to the contribution of the alternative A_j to the realization of the decision factor Ck is:	**then $d_{ij}(k)$ =**
Equal	1
Between equal and moderately higher (small)	2 (1/2)
Moderately larger (small)	3 (1/3)
Between moderately larger (small) and much larger (small)	4 (1/4)
Larger	5 (1/5)
Between much bigger (small) and very big (small)	6 (1/6)
Very large	7 (1/7)
Between very large (small) and extremely large (small)	8 (1/8)
Extremely large	9 (1/9)

Step 1 - It consists in comparing the pairs of decisional alternatives A_1-A_3, according to each decision criterion C_1-C_9, in order to hierarchy them in relation to the respective criterion, [14]. In this sense, are constructing raw matrices of comparison $D^{(k)}$, $(1 \leq k \leq 9)$.

The process has two sub-steps:

a. Construction of raw matrices;
b. Normalization of raw matrices.

In the construction of the raw matrices for each decision criterion C_k $(1 \leq k \leq 9)$ we obtain the quadratic matrix of order 3, $D^{(k)} = \left\{d_{ij}^{(k)},\ 1 \leq i \leq 3, 1 \leq k \leq 9\right\}$. Thus, the element in line i column j of this matrix $d_{ij}^{(k)}$ is a number that compares the contribution of the decisional alternative A_i with the contribution of the decisional alternative A_j to the satisfaction of the decision factor C_k, $(1 \leq k \leq 9)$. By convention it is considered that:

- $d_{ij}^{(k)} > 1$ if the contribution of the alternative A_i to the decision criterion Ck is greater than the contribution of alternative A_j;
- $d_{ij}^{(k)} < 1$ if the contribution of the alternative A_i to satisfy the decision criterion Ck is less than the contribution of the alternative A_j;
- $d_{ij}^{(k)} = 1$ if the alternatives A_i and A_j equally satisfy the decision criterion C_k.

The elements of the matrix $D^{(k)}$ have the following obvious properties $d_{ij}^{(k)} = \frac{1}{d_{ji}^{k}}$ and $d_{ii}^{(k)} = 1$, for $1 \leq i \leq 3, 1 \leq j \leq 3$, [15].

In the following sub-step, the gross decisional matrix is normalized by performing the following calculations:

- sums calculation $s_j^{(k)}$ $(1 \leq j \leq 3)$, on columns;
- dividing each element $d_{ij}^{(k)}, 1 \leq i, j \leq 3$ by the sums of its column $s_j^{(k)}$;
- performances calculation as averages of the items on each line, according to formula 1.1, which are written in an additional column.

$$p_i^{(k)} = \frac{1}{3} \sum_{j=1}^{3} \frac{d_{ij}^{(k)}}{s_j^{(k)}} \quad (1)$$

Step 2 - has as main aim the prioritizing the decision criteria, in order to provide additional information on their contribution to the achievement of the final objective, respectively the choice of a safety helmet adequate for the mechanical locksmith workplace. The comparison matrix $D^{(C)}$ has order 9 - equal to the number of criteria, and its elements $d_{ij}^{(c)}$ are numbers (notes from 1÷9) that compare the importance of the decision factor C_i with the decision factor C_j $(1 \leq i, j \leq 9)$. The calculation rules are similar like at Step1. The performance is written in the form of a column type matrix (P) formed by the elements p_i.

Step 3 of the method combines the results obtained in steps 1 and 2 to produce a general ranking of each decisional alternative A_i $(1 \leq i \leq 3)$, in relation to the decision criteria C_j $(1 \leq j \leq 9)$, [16]. Thus, the results are exposed in a matrix of performance D containing columns - for decision criteria and lines - for alternatives: $D = \left\{d_{ij}, 1 \leq i \leq 3, 1 \leq j \leq 9\right\}$.

The element d_{ij}, being at the intersection of the line of the decisional variant A_i $(1 \leq i \leq 3)$ with the column of the decision criterion C_j $(1 \leq j \leq 9)$ is the performance of the decisional variant A_i in relation to the decision criterion C_j, taken from line i and the column of consequences of the comparison matrix D(j) (the hierarchising of decisional alternatives in relation with the decisional criterion C_j, constructed in step 1).

The general performance, represented matrixial by the matrix S is calculated by multiplying the performance matrix $D_{(3x9)}$ by the column type matrix P -of the performance of the criteria (consisting of the elements p_i in step 2 4), according to the relation, [17]:

$$\{S\} = \{D\}x\{P\} \quad (2)$$

It is obvious that the elements of the matrix:

$$0 \leq s_i \leq 1, (1 \leq i \leq 3) \quad (3)$$

$$\sum_{i=1}^{3} s_i = 1 \quad (4)$$

By using the scores column, respectively by hierarchizing the decisional alternatives, the optimal decision is obtained, which implies the selection of the alternative, characterized by the highest score.

3 Results

In Step 1, each alternative was compared with the other alternatives in relation to each criterion, in part. In order to easily perform the matrixial calculation, we worked in the form of a table. Exemplifying, in table 3 are presented the raw matrix and the normalized matrix $D^{(5)}$, obtained by comparing the alternatives A_i with A_j, in relation to the criterion C_5, using the steps listed previously.

From the normalized matrix $D^{(5)}$ it is observed that the greatest performance has the alternative A_2, in relation to the criterion C_5 (shock absorption capacity). Analogously, the performances of each alternative were obtained in relation to each criterion C_i ($1 \le i \le 9$).

Table 3. Alternative comparison matrix $D^{(5)}$.

Shock absorption capacity

Comparison of alternatives - depending on the criterion: shock absorption capacity

Matrix $D^{(5)}$ -raw			
Alternative	**A_1**	**A_2**	**A_3**
A_1	1.0000	0.2000	0.3333
A_2	5.0000	1.0000	3.0000
A_3	3.0000	0.3333	1.0000
$s_j^{(k)}$	**9.0000**	**1.5333**	**4.3333**

Matrix $D^{(5)}$ - normalized				
Alternatives (initial)	**A_1**	**A_2**	**A_3**	**Consequences (performances)**
A_1	0.1111	0.1304	0.0769	0.1062
A_2	0.5556	0.6522	0.6923	0.6333
A_3	0.3333	0.2174	0.2308	0.2605
Total	**1.0000**	**1.0000**	**1.0000**	**1.0000**

In step 2, after the calculation of the raw matrix and the normalized matrix, there are obtaining the performances of the criteria as averages of the elements from each line of the matrices. The results are presented in tabular form.

In the table 4 are presented the comparison matrices of the C_i criteria ($1 \le i \le 9$) in order to establish the criterion that has the significant contribution on the final decision, namely the one that has the highest p_i performance. The performance of each criterion in relation to the other criteria are presented in the p_i performance column.

In step 3 the product of the matrices D and P is presented tabulated - see table 5. The decision matrix D has an additional line containing the weights of the decision factors, namely the ratios column of the matrix $D^{(C)}$ built in step 2 and which is bordered with a column containing the general scores of the alternatives.

The result of the product between the matrices D and P is presented in the column called score, where the elements s_i ($1 \le i \le 3$), represent the scores (ratio averages) of the decisional variants A_i ($1 \le i \le 3$). It can be seen that the alternative variant A_2 has the highest evaluation factor (the best score), therefore the recommended decision is the helmet no. 2.

Table 4. Criteria comparison matrix.

Comparison of the importance of the criteria - in relation to the achievement of the general objective										
Matrix $D^{(C)}$ -raw										
The decision criterion	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**	
C_1	1.000	3.000	0.167	0.167	0.143	0.125	0.125	0.250	0.250	
C_2	0.333	1.000	0.200	0.333	0.125	0.143	0.125	0.250	0.200	
C_3	6.000	5.000	1.000	0.500	0.200	0.333	0.167	0.500	0.500	
C_4	6.000	3.000	2.000	1.000	0.200	0.500	0.250	0.333	0.333	
C_5	7.000	8.000	5.000	5.000	1.000	3.000	2.000	7.000	7.000	
C_6	8.000	7.000	3.000	2.000	0.333	1.000	0.250	6.000	5.000	
C_7	8.000	8.000	6.000	4.000	0.500	4.000	1.000	6.000	7.000	
C_8	4.000	4.000	2.000	3.000	0.143	0.167	0.167	1.000	0.500	
C_9	4.000	5.000	2.000	3.000	0.143	0.200	0.143	2.000	1.000	
$s_j^{(c)}$	**44.333**	**44.000**	**21.367**	**19.000**	**2.787**	**9.468**	**4.226**	**23.333**	**21.783**	
Matrix $D^{(C)}$-normalized										
The decision criterion	**C_1**	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**	**Performances p_i**
C_1	0.0226	0.0682	0.0078	0.0088	0.0513	0.0132	0.0296	0.0107	0.0115	0.0248
C_2	0.0075	0.0227	0.0094	0.0175	0.0449	0.0151	0.0296	0.0107	0.0092	0.0185
C_3	0.1353	0.1136	0.0468	0.0263	0.0718	0.0352	0.0394	0.0214	0.0230	0.0570
C_4	0.1353	0.0682	0.0936	0.0526	0.0718	0.0528	0.0592	0.0143	0.0153	0.0626
C_5	0.1579	0.1818	0.2340	0.2632	0.3588	0.3169	0.4732	0.3000	0.3213	0.2897
C_6	0.1805	0.1591	0.1404	0.1053	0.1196	0.1056	0.0592	0.2571	0.2295	0.1507
C_7	0.1805	0.1818	0.2808	0.2105	0.1794	0.4225	0.2366	0.2571	0.3213	0.2523
C_8	0.0902	0.0909	0.0936	0.1579	0.0513	0.0176	0.0394	0.0429	0.0230	0.0674
C_9	0.0902	0.1136	0.0936	0.1579	0.0513	0.0211	0.0338	0.0857	0.0459	0.0770
Sume	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	

Table 5. Performances matrix.

The alter-native	**Decisional criteria**									**Score s_i**
	C_1	**C_2**	**C_3**	**C_4**	**C_5**	**C_6**	**C_7**	**C_8**	**C_9**	
	$p_1 =$ 0.0248	**$p_2 =$ 0.0185**	**$p_3 =$ 0.0570**	**$p_4 =$ 0.0626**	**$p_5 =$ 0.2897**	**$p_6 =$ 0.1507**	**$p_7 =$ 0.2523**	**$p_8 =$ 0.0674**	**$p_9 =$ 0.0770**	
A_1	0.7234	0.6905	0.6333	0.6333	0.1062	0.5907	0.3333	0.5571	0.0790	0.3541
A_2	**0.2062**	**0.0588**	**0.2605**	**0.2605**	**0.6333**	**0.3338**	**0.3333**	**0.3202**	**0.1527**	**0.3886**
A_3	0.0704	0.2507	0.1062	0.1062	0.2605	0.0755	0.3333	0.1226	0.7683	0.2574
Total	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.000

4 Conclusion

The AHP analysis method allows decision makers to structure a problem in a hierarchy, helping them to understand and simplify a given problem.

In the case of our paper, the AHP method allowed the choice of the best helmet following an analysis performed depending of 9 criteria. Obviously, in the evaluation process, can be taken into account a smaller or larger number of decisional criteria

The method can be considered a flexible and powerful tool for managing multicriteria quantitative and qualitative problems that helps the worker who deals with problems of occupational safety and health issues to make optimal choices justified. The disadvantage of the AHP method is that it involves a large number of mathematical calculations and especially a large number of comparisons in pairs. This aspect requires a long computation time that increases in proportion to the number of alternatives and criteria.

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