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 unique criterion of synthesisation, [10].

| Alternative | Price (€) | MC (€) | QM | Design | Force [kN] | Mass [g] | IER [J] | LC [mA] | RT [°C] |
|-------------|-----------|--------|-----|--------|------------|----------|--------|--------|--------|
| A1: Safety helmet 1 | 45 | 24 | Very high quality | Ergonomics-special | 3,6 | 360 | 30 | 1,2 | -30 |
| A2: Safety helmet 2 | 33 | - | High quality | Ergonomic | 4,8 | 338 | 30 | 1,1 | -40 |
| A3: 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.
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 $C_k$ 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, \( D^{(k)} = \{d^{(k)}_{ij}, 1 \leq i \leq 3, 1 \leq k \leq 9\} \). Thus, the element in line \( i \) column \( j \) of this matrix \( d^{(k)}_{ij} \) 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:

- \( d^{(k)}_{ij} > 1 \) if the contribution of the alternative \( A_i \) to the decision criterion \( C_k \) is greater than the contribution of alternative \( A_j \);

- \( d^{(k)}_{ij} < 1 \) if the contribution of the alternative \( A_i \) to satisfy the decision criterion \( C_k \) is less than the contribution of the alternative \( A_j \);

- \( d^{(k)}_{ij} = 1 \) 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 \( d^{(k)}_{ij} = \frac{1}{d^{(k)}_{ji}} \) and \( d^{(k)}_{ii} = 1 \), 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 \( s^{(k)}_j \) \((1 \leq j \leq 3)\), on columns;

- dividing each element \( d^{(k)}_{ij} \), \( 1 \leq i, j \leq 3 \) by the sums of its column \( s^{(k)}_j \);

- performances calculation as averages of the items on each line, according to formula 1.1, which are written in an additional column.

\[
p^{(k)}_i = \frac{1}{3} \sum_{j=1}^{3} \frac{d^{(k)}_{ij}}{s^{(k)}_j}
\]

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 \( d^{(c)}_{ij} \) 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: \( D = \{d_{ij}, 1 \leq i \leq 3, 1 \leq j \leq 9\} \).

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 \( D_{(3\times9)} \) 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, \([17]\):

\[
\{S\} = \{D\}x\{P\}
\]

It is obvious that the elements of the matrix:

\[
0 \leq s_i \leq 1, \ (1 \leq i \leq 3)
\]

\[
\sum_{i=1}^{3} s_i = 1
\]
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 $C_i \ (1 \leq i \leq 9)$.

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

| Comparison of alternatives - depending on the criterion: shock absorption capacity |
|-----------------------------------------------|-----------------|-----------------|-----------------|
| Matrix $D^{(5)}$ - raw                        | $A_1$ | $A_2$ | $A_3$ |
| $A_1$                                         | 1.0000 | 0.2000 | 0.3333 |
| $A_2$                                         | 5.0000 | 1.0000 | 3.0000 |
| $A_3$                                         | 3.0000 | 0.3333 | 1.0000 |
| $s_{ij}^{(k)}$                                 | 9.0000 | 1.5333 | 4.3333 |

| Shock absorption capacity                      | Matrix $D^{(5)}$ - normalized | Consequences (performances) |
|-----------------------------------------------|-------------------------------|-----------------------------|
| Alternatives (initial)                        | $A_1$ | $A_2$ | $A_3$ |                               |
| $A_1$                                         | 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 ($1 \leq i \leq 9$) 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 $s_i \ (1 \leq i \leq 3)$, represent the scores (ratio averages) of the decisional variants $A_i \ (1 \leq i \leq 3)$. 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.

| The decision criterion | C1     | C2     | C3     | C4     | C5     | C6     | C7     | C8     | C9     |
|------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                         | 1.000  | 3.000  | 0.167  | 0.167  | 0.143  | 0.125  | 0.125  | 0.250  | 0.250  |
| C1                     | 0.333  | 1.000  | 0.200  | 0.333  | 0.125  | 0.143  | 0.125  | 0.250  | 0.200  |
| C2                     | 6.000  | 5.000  | 1.000  | 0.500  | 0.200  | 0.333  | 0.167  | 0.500  | 0.500  |
| C3                     | 6.000  | 3.000  | 2.000  | 1.000  | 0.200  | 0.500  | 0.250  | 0.333  | 0.333  |
| C4                     | 7.000  | 8.000  | 5.000  | 5.000  | 1.000  | 3.000  | 2.000  | 7.000  | 7.000  |
| C5                     | 8.000  | 7.000  | 3.000  | 2.000  | 0.333  | 1.000  | 0.250  | 6.000  | 5.000  |
| C6                     | 8.000  | 8.000  | 6.000  | 4.000  | 0.500  | 4.000  | 1.000  | 6.000  | 7.000  |
| C7                     | 4.000  | 4.000  | 2.000  | 3.000  | 0.143  | 0.167  | 0.167  | 1.000  | 0.500  |
| C8                     | 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 |

### Table 5. Performances matrix.

| The alternative | Decisional criteria | Score $s_i$ |
|-----------------|---------------------|-------------|
|                 | $p_1$=0.0226        | 0.0248      |
|                 | $p_2$=0.0075        | 0.0185      |
|                 | $p_3$=0.1353        | 0.1136      |
|                 | $p_4$=0.1353        | 0.0682      |
|                 | $p_5$=0.1579        | 0.1818      |
|                 | $p_6$=0.1805        | 0.1591      |
|                 | $p_7$=0.0902        | 0.1136      |
| A1              | 0.7234              | 0.6905      |
|                 | 0.6333              | 0.6333      |
|                 | 0.1062              | 0.1062      |
|                 | 0.1062              | 0.1062      |
|                 | 0.0902              | 0.0902      |
| A2              | 0.2062              | 0.0588      |
|                 | 0.2605              | 0.2605      |
|                 | 0.2605              | 0.2605      |
|                 | 0.2605              | 0.2605      |
|                 | 0.0902              | 0.0902      |
| A3              | 0.0704              | 0.2507      |
|                 | 0.1062              | 0.1062      |
|                 | 0.1062              | 0.1062      |
|                 | 0.1062              | 0.1062      |
|                 | 0.0902              | 0.0902      |
| Total           | 1.0000              | 1.0000      |
|                 | 1.0000              | 1.0000      |
|                 | 1.0000              | 1.0000      |
|                 | 1.0000              | 1.0000      |
|                 | 1.0000              | 1.0000      |
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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