Karol DURCZAK
Poznań University of Life Sciences, Institute of Agricultural Engineering
ul. Wojska Polskiego 28, 60-637 Poznań (Poland)
e-mail: kdurczak@up.poznan.pl

HIERARCHISATION OF QUALITY PARAMETERS OF AGRICULTURAL MACHINES BY PAIRWISE COMPARISON

Summary

Global quality of the products, including agricultural machines, is a resultant of many characteristics, part of which are of measurable and another part – of non-measurable nature. This incommensurable character of quality traits makes that objective consideration of the overall product quality assessment is a difficult task. That is why the technique of pairwise evaluation employed in analytic hierarchy process (AHP) studies was used to solve this problem. In addition, the possibilities of the Expert Choice program employed to assist multicriterial decision-making processes in various fields were also presented.

HIERARCHIZACJA PARAMETRÓW JAKOŚCIOWYCH MASZYN ROLNICZYCH PRZEZ PORÓWNYWANIE PARAMI

Streszczenie

Globalna jakość wyrobów, w tym także maszyn rolniczych, jest wypadkową wielu cech, z których część ma charakter mierzalny, cześć zaś niemierzalny. Ta niewymierność cech jakościowych sprawia, że obiektywne rozważanie, co do ważności tych cech jest zadaniem trudnym. Dlatego do rozwiązania problemu wykorzystano technikę porównywania parami czynników, stosowaną w metodzie analizy hierarchicznej AHP. Zaprezentowano także możliwości programu Expert Choice, który znajduje zastosowanie przy wspomaganiu wielokryterialnych procesów decyzyjnych w różnych dziedzinach.

1. Introduction

Numerous available methods can be employed to assess the quality of various forms of products [8, 9, 10]. Literature from the field of quality engineering provides a number of procedures making it possible to assess quality but only some of them make quality quantification possible. This approach to global product quality assessment allows their arrangement while carrying out comparative tests. In the case of such products as agricultural machines, numerical expression of their final quality is a necessity.

The optimal choice of a machine to a given farm should be the result of long-term and careful considerations, meticulous analyses as to the importance of individual criteria whereas a purely intuitive approach is usually burdened with faults. Such decisions tend to defy logical justification and their usefulness in decision-making processes is debatable and, consequently, brings doubtful final effects, especially economical.

Irrespective of the applied method of quality evaluation, it will always involve a stage of hierachisation of traits or groups of similar traits of a given product [2, 3, 5, 6, 14]. The weights allocated to individual traits are usually of very subjective nature. In order to increase the assessment reliability of weight coefficients, expert knowledge from a given field is frequently employed. In the case of the mean quality rating (MQR), an identical coefficient equalling 1 is allocated to individual criteria [2, 9] since it is difficult to decide which criterion exerts the strongest impact on the customer's decision at the moment of purchase of a new machine. Nevertheless, weights of criteria continue to remain the resultant of individual assessments of individual experts. Then it is possible to apply the technique of a simultaneous comparison of two traits used in the method of the analytic hierarchy process (AHP).

The interest in the AHP method was stimulated by investigations on methods and tools associated with the analysis of the risk of exploitation of complex technical objects. The method of problem hierarchical analysis developed in 1980 by Thomas Saaty [12] is one of the multicriterial methods of hierarchical analysis of decision problems. It makes possible decomposition of a complex decision problem and elaboration of a final ranking for a finite set of variants.

The AHP method takes into consideration the specificity of psychological evaluation processes which are, first and foremost, of relative and hierarchical nature. Frequent applications of the method to assist economic, technical and social decisions confirm its usefulness, especially in those applications where a significant proportion of assessment criteria are of quality nature and the experience of the person who is involved in the evaluation provides the main source of assessment which is subjective in nature. The AHP method is based on the graphic modelling of target hierarchy with the aim to present the considered problem in the form of a hierarchical tree allowing the description of the decision structure of the problem. On the other hand, the realisation of the main target by each of the variants results from the fulfilment of intermediate targets expressed by criteria that correspond to them.

The AHP method confirms its usefulness particularly in situations when:

- Hierarchy of the assessment criteria occurs which represent different levels of complexity which is associated with the hierarchy of targets or expectations of advantages;
- Majority of variant assessment criteria is not of quantity but quality nature and, what is more, a considerable proportion of evaluations is burdened by the subjectivity of judges (the person who makes decisions),
- Complete comparability of variants occurs, i.e. when, for example, the comparison and assessment take place in a set of variants that belong to the same class [1].

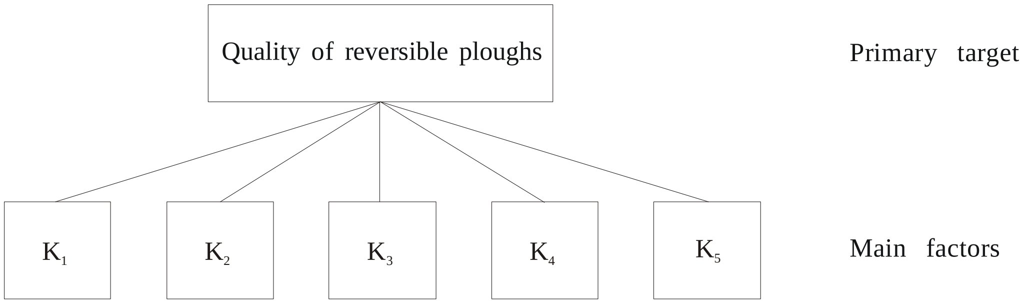

Fig. 1. General scheme of the hierarchical structure of plough quality

After defining a specific decision problem (usually in the form of factor hierarchy), the next step in the AHP method is to determine assessments for the impact factors by comparing them in pairs. The application of such computer programs as Expert Choice or www.AHPproject.com facilitates decision making. It takes the decision-maker through a series of pairwise comparisons and, consequently, makes it possible to obtain aggregated weights of variants and, hence, their ranking. In such situation, the best variant will then have the highest weight.

Practical examples of the application of the AHP method confirm that it can be used at estimate weights of the main criteria of agricultural machines on which their global quality depends [1, 11, 4, 15, 16].

2. Research objective

Taking as an example reversible ploughs, the usefulness of the method of pairwise comparison of quality traits to determine the hierarchy of factors affecting the global quality of agricultural machines was evaluated. The investigations were carried out on the basis of different ways of calculation of weights employed in AHP methods. In addition, the results were checked with the assistance of the Expert Choice application used for computer-aided decision processes.

3. Material and methods

Global quality of agricultural machines is affected by many measurable and non-measurable traits which can be grouped into the so-called theme groups of similar traits. It is these 'theme groups', referred to as 'principal factors' in the AHP method and 'principal criteria' in this study, that constitute the object of this research project. Simulation investigations were carried out on reversible ploughs whose traits were grouped into the following principal criteria:

- Functionality (K_1): total working width, roll-over time, number of lubrication points, weight, possibility of mounting consecutive ploughs, distance between ploughs, type of safety devices against overload, type of share and mouldboard, versatility, required oil connection, height of the frame, wheel protrusion at the smallest/largest working width, power requirement;
- Ergonomics and industrial safety (K_2): frame blockade, instruction manual, catalogue of spare parts, lighting, replacement of the support wheel, tool box, wiring, working width indicator, behaviour during driving, warning and information signs;
- Styling (K_3): quality of welding and coat of paint;
- Reputation (K_4);
- Price (K_5).

In order to elaborate criterion ranking, it was necessary to develop a hierarchical model of the considered decision problem (Fig. 1).

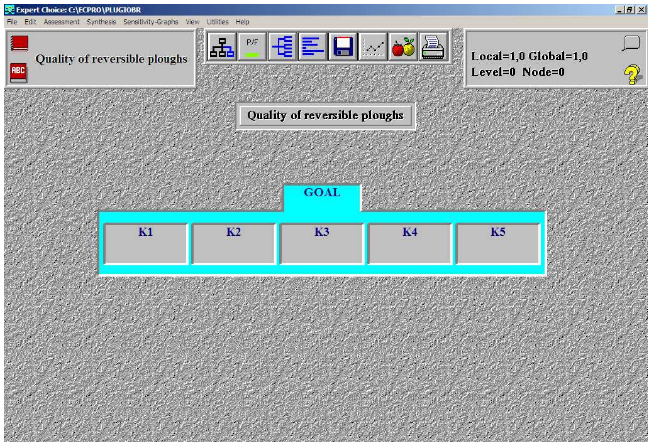

Fig. 2. Hierarchical model of the decision problem (choice of optimal machine) in the Expert Choice program

The principal target in this case was the global quality of reversible ploughs, while the quality criteria assumed earlier (K_1 – K_5) described main factors. Criteria represented lower order targets (sub-criteria) whose realisation enhanced the achievement of the principal target and were divided into traits (partial factors) which, for simplification purposes, were not included in the above scheme.

Once the hierarchical model of a problem was elaborated in the AHP method by means of pairwise comparison, the relative significance of criteria was determined as a degree of their relative domination. An expert (or decision-maker) assigned each pair a number. The scope of acceptable domination values ranged from 1 to 9 and it was recommended that scores should be given odd-numbered values. Even-numbered values were allocated only in the case when traits needed to be differentiated more precisely. Table 1 presents the description of a 9-score scale assessment.

The indicator of the relative significance of the K_i over K_j criterion was expressed by such value that $a_{i,j} \in \{1, 2, 3, ..., 9\}$. Factors subjected to ranking were then grouped into a square matrix $A = [a_{ij}]$ of n x n dimension where n was the number of assumed main criteria. Additionally, the following dependence for the A matrix expression remained in force:

$$a_{ij} = \frac{1}{a_{ji}} \qquad (1)$$

for i, j = 1,2, ..., n.

Table 1. Scale of relative importance for pairwise comparison according to Saaty's method

Indicator	Description	Explanation
1	Identical importance	Both factors equally contribute to the achievement of the target
3	Slight advantage	Opinion and experience prefer one factor over the other one
5	Strong advantage	Opinion and experience strongly prefer one factor over the other one
7	Very strong advantage	One factor is very strongly preferred over the other one and practice confirms this advantage
9	Absolute advantage	The advantage of one factor over the other is absolute and is confirmed to the highest degree

The matrix degree equalled the number of compared elements, whereas weights along the diagonal always corresponded to the value of 1.

Weights of the quality criteria of agricultural machines were determined with the assistance of Satty's method and the method of geometrical means.

In order to determine weights (priority vectors) of the main factors using the Satty's method, it was necessary:
1. To standardise matrix A by dividing each element by the sum of elements of the column,
2. To calculate arithmetic means for each row of new matrix which were the sought w_i weights.

A different method of weight determination was a geometric mean calculated for each row of matrix A in the following way [7]:
1. Calculation of geometrical means r_i for each row of matrix A,
2. On the other hand, weights of criteria were obtained by dividing geometric means by their sum ($\sum r_i$).

Weight calculations can also be carried out employing special software for AHP. In this study, a student version of the Expert Choice v.9.5 application [13] was used.

In order to consider the ranking process in the AHP method as correct, it was essential to obtain the required estimation compatibility expressed by the so called coefficient of inconsistency CI of the comparison matrix. This coefficient made it possible to check if the obtained estimates violated the principles of preference stability and it was determined from the dependence:

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (2)$$

where:

λ_{max} – Maximum own value of the comparison matrix of the order of n,
n – number of compared objects.
The value of the CI index should not exceed 0.1.

4. Results

Employing the method of pairwise factor serial comparison, the expert (in this case, the author) assigned scores of criterion domination of reversible ploughs (Table 2).

Table 2. Scores of pairwise comparison of reversible plough quality criteria

Criteria	K_1	K_2	K_3	K_4	K_5
K_1	**1.000**	3.000	9.000	3.000	3.000
K_2	0.333	**1.000**	9.000	3.000	3.000
K_3	0.111	0.111	**1.000**	0.200	0.111
K_4	0.333	0.333	5.000	**1.000**	1.000
K_5	0.333	0.333	9.000	1.000	**1.000**

The weights of w_i criteria determined according the Satty's method as well as auxiliary calculations made with the aid of the MS Excel spreadsheet are presented in Table 3.

Calculation results were checked with the assistance of the Expert Choice program. Next stages of the work with the program for AHP are shown in the figures presented below which are screen pictures from the computer monitor. Figure 2 illustrates one of the stages of construction of the model of the hierarchic process.

The overriding goal was "Quality of reversible ploughs" which depended on five main criteria K_1-K_5. The next stage was the assessment of quality criteria by their pairwise comparison (Fig. 3).

Table 3. Way of weight criteria K_1-K_5 determination of reversible ploughs and their values

Criteria	K_1	K_2	K_3	K_4	K_5	K_1	K_2	K_3	K_4	K_5	w_i
K_1	1.000	3.000	9.000	3.000	3.000	0.474	0.628	0.273	0.366	0.370	0.422
K_2	0.333	1.000	9.000	3.000	3.000	0.158	0.209	0.273	0.366	0.370	0.275
K_3	0.111	0.111	1.000	0.200	0.111	0.053	0.023	0.030	0.024	0.014	0.029
K_4	0.333	0.333	5.000	1.000	1.000	0.158	0.070	0.152	0.122	0.123	0.125
K_5	0.333	0.333	9.000	1.000	1.000	0.158	0.070	0.273	0.122	0.123	0.149
Total	2.111	4.778	33.000	8.200	8.111						1.000

Similar final results of weight coefficients were obtained using the method of geometrical means (Table 4).

Table 4. Weight criteria determined using the method of geometrical means

Criteria	K_1	K_2	K_3	K_4	K_5	r_i	w_i
K_1	1.000	3.000	9.000	3.000	3.000	3.000	0.428
K_2	0.333	1.000	9.000	3.000	3.000	1.933	0.276
K_3	0.111	0.111	1.000	0.200	0.111	0.194	0.028
K_4	0.333	0.333	5.000	1.000	1.000	0.889	0.127
K_5	0.333	0.333	9.000	1.000	1.000	1.000	0.143
Total						7.016	1.000

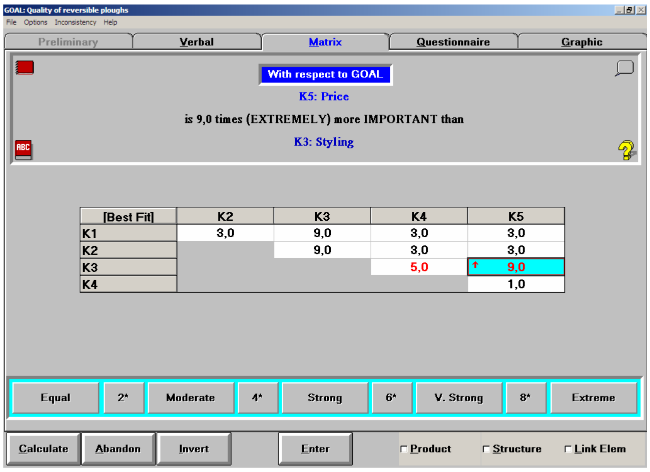

Fig. 3. Matrix of criterion pairwise comparison

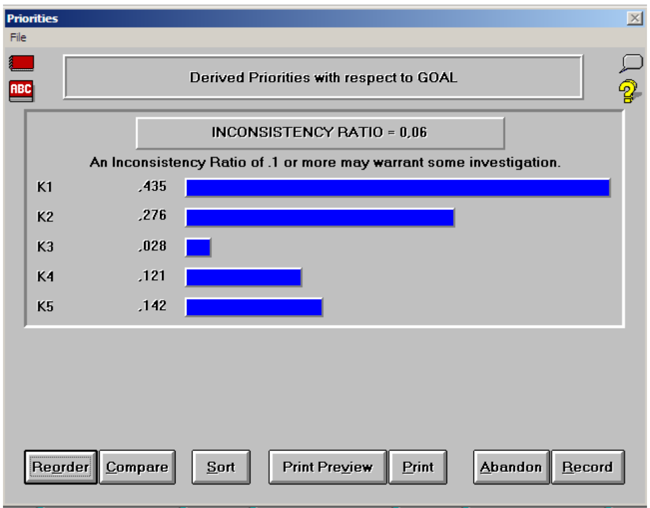

Fig. 4. Inconsistency ratio of estimates and weight for the assessment criteria of plough quality

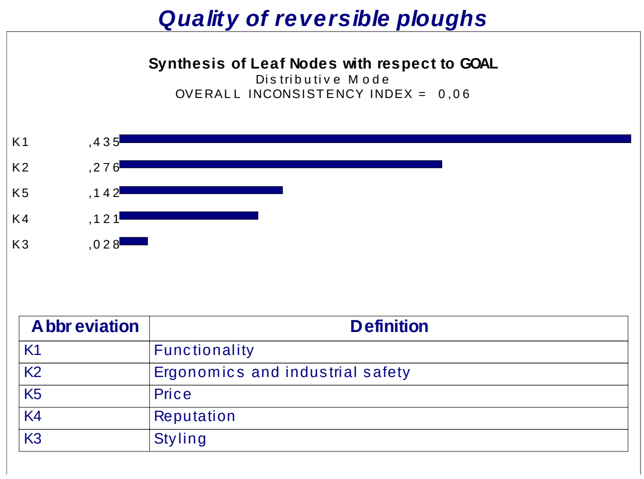

Fig. 5. Stage report from the Expert Choice program

Red digits in the Table cell indicate other than standard direction of the domination. For example, in the case of ploughs, functionality had an overriding advantage over style (black 9), whereas reputation had a strong advantage over style (red 5).

Figure 4 presents calculated weight values together with significance coefficients CI.

Since CI < 0.1, hence the results of ranking could be accepted as final. The first stage of work with the Expert Choice program (input data and criteria sorted according their importance) can be summed up by a recapitulation ready for printing (Fig. 5).

Therefore, it can be said that according to experts, the most important criterion in assessing the quality of reversible ploughs was their functionality and the least important one – their external appearance. This arrangement of criteria was justified logically because these criteria comprised the highest amount of traits important for agricultural machines.

5. Conclusions

The performed simulation investigations intended to assign ranks to quality criteria of agricultural machines made it possible to draw the following final conclusions:

1. The presented method of serial pairwise comparison made it possible to determine relative significance of the considered impact factors – in this case, criteria of reversible ploughs quality evaluation. Therefore, it can be useful for the evaluation and, consequently, ranking of criteria affecting the global quality of different groups of agricultural machines.
2. Among important advantages of the AHP method in comparison with other multifactorial methods of decision aiding is the fact that it does not require direct assignment of weights to individual criteria but operates exclusively on relative assessment of the compared elements. All comparisons are conducted on pairs on the basis of objective or subjective assessment of the expert (decision-maker).
3. The presented different techniques of criteria evaluation, i.e. using Saaty’s method as well as the method of geometrical means gave similar results. Therefore, the choice of a specific technique depends exclusively on preferences of the decision-maker.
4. The necessary requirement regarding the application of the comparative method is full information from the expert. If there is a problem with missing assessments, then it is necessary to employ extension of this method employing the arithmetic of diffuse numbers.
5. Knowing evaluation algorithms, it is possible to simplify and automate calculations using, for example, a spreadsheet. Another solution is to apply a special application utilising the AHP method.
6. Among advantages of the Expert Choice computer software to aid decision processes employed to hierarchise quality parameters of agricultural machines by means of pairwise comparison is graphic presentation of results which facilitates the analysis of the considered problem.

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