Beata BELINA, Ludmiła ŁOPACIŃSKA
Institite for Sustainable Technologies – National Research Institute
beata.belina@itee.radom.pl, ludmila.lopacinska@itee.radom.pl

SETTING OF CRITERIA IN THE INNOVATIVENESS LEVEL ASSESSMENT METHOD OF TECHNOLOGICAL SOLUTIONS

Key words

technological solution, innovativeness level assessment, assessment criteria, AHP method.

Abstract

The article presents the *Analytic Hierarchy Process (AHP)* method used for the development of the innovativeness level assessment method (PI) of technological solutions. The need for the development of such a method stemmed from the *"Innovative Systems of Technical Support for Sustainable Development of Economy"* strategic research programme. The AHP method helps to assign weights to the criteria of the innovativeness assessment level method. The AHP method is dedicated to support the decision making process and to facilitate the assessment with the use of multicriteria, especially in the case of qualitative criteria subjectively assessed by the experts.

The developed the PI method significantly supports the process of knowledge transformation and the transfer of advanced technologies in the area of the development and the maintenance of machines and technical devices. The use of this assessment improves in the competitiveness of the economy.

Introduction

The market of the 21st century should be more integrated, open, and competitive. In order to face up to globalisation, the potential of the market

should be exploited, mainly through the improvement of the level of knowledge and innovation. Its optimisation should be directed at the outcomes, and in order to assess these effects, a new approach should be created.

How to assess the level of innovativeness of a product? There are many different approaches to this issue; however, it is not possible to state which solution is the most efficient and the most effective.

The state-of-the-art indicates different methods used in the assessment of the innovativeness [1]. We can start from the most traditional method – a descriptive method. It is very precise, however it is also very expensive and time-consuming [2].

Another method, which serves to measure the innovativeness level, is the indication of the number of innovations. This method was proposed by Ch. Freeman from the Sussex University in the UK. It was used in different sectors of the economy, but it was not very precise and therefore it was precluded [3].

The innovativeness level can also be measured with the use of the surveys, e.g. *Community Innovation Survey* [4]. The method is very popular in the EU Member States. In other countries, the surveys are also used. Although the surveys may lack in precision, they show a picture of the intensity of the innovations in different sectors.

The next method for the measurement of innovativeness is the statistical data on patents [5]. The method is popular, among others, in the European Union and in the United States. The biggest disadvantage of this method is that not all innovations are patented, and the number of patents does not reflect the actual number of innovations.

The estimation of the expenditures on the R&D activity is yet another way to measure the number of innovations and the level of innovativeness [6]. For instance, many enterprises in the UK are obliged to give information on the expenditures for their R&D. The method has some disadvantages, e.g. not all companies are willing to reveal such data; however, that does not mean that they do not implement innovations. Moreover, a high level of research does not guarantee a high level of innovations.

The comparative analysis based on the Oslo Manual aims at harmonising quantitative data on innovations and innovativeness [7]. The manual includes the methodological directions on how to qualify the research of technological innovations. It also includes information on the diversification of the level of innovations, which enables the identification of the differences between bodies creating innovations *(innovation creators)* and those who use the innovations *(innovation adopters)* [8].

The estimation of the *Summary Innovation Index* is also a way to measure innovativeness [9]. It is one of the most important indicators within the study on innovativeness. The analysis employs such indicators as the extent of the research, the effectiveness of the industry, the development of the technology,

the R&D research, the development of technologies and commercial enterprises, and the generation of the welfare or capital investment.

Innovativeness can also be measured with the use of the multi-criteria methods, such as the AHP method. It is one of the outstanding management tools dealing with the complication of multi-criteria decision problems. It simplifies the solution of not only the qualitative problems, but also quantitative ones. There are several studies utilizing the AHP method for computing the relative importance weight among various key determinants [10].

This article is focused on the AHP method, since it stimulates the correct development of the elements included in the method of the innovativeness level assessment.

1. The Analytic Hierarchy Process (AHP) [11]

The Analytic Hierarchy Process developed by Saaty is a method that enables the ranking of multiple criteria and supports the decision making process. The wide applicability of the AHP method stems from its simplicity, flexibility, and the possibility to integrate with other methods used for solving advanced and very complex multi-criteria decision problems. A wide application area of the AHP method has been studied in a number of papers. The complexity of the literature review of the AHP applications was presented in Ho and Vaidya.

To make a decision in a systematic way, the analytic process is decomposed into the following basic steps:
1.   Definition of the problem;
2.   Structuring the problem in a hierarchy of levels constituting the goal, criteria and alternatives;
3.   Construction of a set of pairwise comparison matrices and comparing each element in the corresponding level by using the comparison scale;
4.   Calculations to find the priority vector;
5.   Checking the consistency of the matrix; and,
6.   Calculations final ratings.

The scale, which is used in judgment making by pairwise comparisons among the elements, is given in Table 1. The pairwise comparisons are carried out for all elements to be considered.

Table. 1. Scale for pairwise comparisons

Intensity of importance(a_{ij})	Definition	Explanation
1	Equal importance	A_i and A_j elements are equally important
3	Weak importance	A_i is slightly more important than A_j
5	Strong importance	A_i is strongly more important than A_j

Intensity of importance(a_{ii})	Definition	Explanation
7	Very strong importance	A_i is very strongly more important than A_j
9	Extreme importance	A_i is extremely preferred than A_j
2, 4, 6, 8	Intermediate values	Used when compromise is needed between two adjacent judgments
Reciprocals: 1/2, 1/3, …, 1/9	If A_j element is favoured in comparison with A_i then the reciprocal value is used	

Source: Authors.

The quality and the reliability of the judgment process and final results are expressed by the matrix consistency. The consistency ratio (CR) is used to check consistency of the matrix:

$$CR = \frac{CI}{RI} \tag{1}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2}$$

where: n – dimension of the matrix;
CI – consistency index;
RI – random index (that depends on matrix dimension);
λ_{max} – maximum eigenvalue (calculated for a given matrix).

The matrix is consistent if the *CR* value is less than 0.10. If the consistency ratio exceeds 0.10, the matrix is inconsistent and then the judgment process must be revised.

2. The innovativeness level assessment method

The innovativeness level assessment method (PI)[1], developed at the Institute for Sustainable Technologies – National Research Institute in Radom, enables one to test the level of the innovativeness of technological solutions at different stages of their development and to make a comparative analysis of the assessment results at the previous stages of the solution development process.

The authors proposed ten (10) criteria, which enable the assessment of the innovativeness level of the solutions from the area of advanced technologies (see Table 2).

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[1] *Innovative Systems of Technical Support for Sustainable Development of Economy* strategic research programme.

Table 2. Criteria of the innovativeness level assessment of technological solutions

No.	Criteria of the innovativeness level assessment
1	Originality / novelty of a solution
2	Character of an innovation
3	Scientific verification of a solution
4	Scope of the use of other advanced technologies
5	Practical verification of a solution
6	Sustainability of a solution
7	Areas of application of the solution
8	Impact on the environment and safety
9	Potential for development of the solution
10	Diffusion of a solution

Source: Authors.

Five variants of the response are proposed; however, due to the possibility of the appearance of "the error of the central tendency," the variants are described in details. They are not short answers, as high, average, or low (see Table 3).

Table 3. The example of the assessment criterion and the possible variants of responses

Criterion	Variants of responses
Originality / novelty of a solution	Analogous or similar solutions exist on the market.
	A solution of a low originality level in comparison with the solutions existing on the market.
	An original solution within a specific sector of the economy for which there are similar solutions existing in other sectors of the application.
	A solution of a high originality level for which some similar solutions are identified.
	A solution of the highest originality level for which the analogous solutions are not identified.

Source: Authors.

The authors proposed the assessment ranking from 1–9 (odd numbers). The variants of the responses are arranged in order from the least favourable (the lowest value) to the most favourable (the highest value). The algorithm of the innovativeness level assessment of the technological product is presented in Figure 1.

The number of the detailed criteria is limited to a maximum of ten criteria, which is in accordance with the AHP method. Priorities are determined through executing paired comparisons of criteria at the main criteria level and the detailed criteria level. Judgments are made by the interdisciplinary team of experts. Priority vectors in matrices are determined in the process of computation.
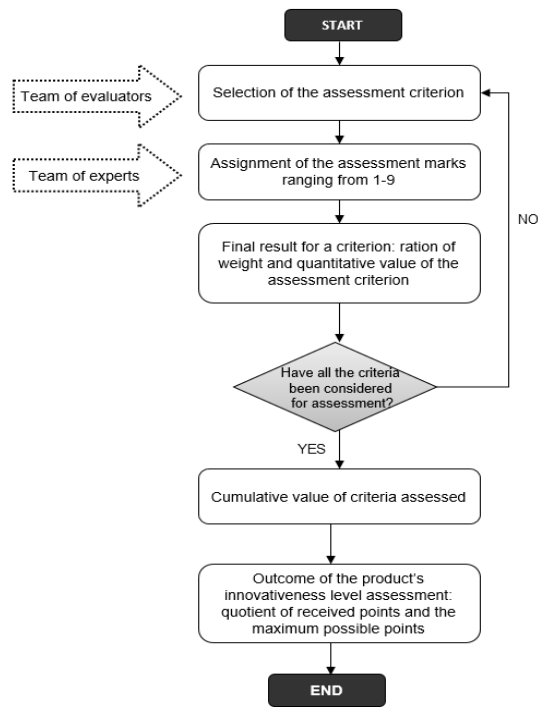
Fig. 1. The algorithm of the innovativeness level assessment of a technological product
Source: Authors.

Paired comparison matrices for the detailed criteria are shown (see Tables 4–5).

Table 4. Paired comparison matrix for detailed criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Priority vector
C1	1	2	3	5	3	3	6	7	5	7	0.260
C2	1/2	1	3	5	3	3	6	7	5	7	0.227
C3	1/3	1/3	1	5	2	5	5	5	5	5	0.162
C4	1/5	1/5	1/5	1	1/3	1/3	1	2	1/3	1/3	0.031
C5	1/3	1/3	1/2	3	1	3	2	5	5	5	0.116
C6	1/3	1/3	1/5	3	1/3	1	1	1	1	1	0.049
C7	1/6	1/6	1/5	1	1/2	1	1	3	3	3	0.055
C8	1/7	1/7	1/5	1/2	1/5	1	1/3	1	1/4	1/4	0.022
C9	1/5	1/5	1/5	3	1/5	1	1/3	2	1	2	0.043
C10	1/7	1/7	1/5	3	1/5	1/3	1/3	4	1/2	1	0.034
											1.000

Consistency ratio: $CR = 0.032 < 0.1$.
Source: Authors.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	Average
C1	0.298	0.412	0.345	0.169	0.279	0.161	0.261	0.189	0.192	0.222	0.253
C2	0.149	0.206	0.345	0.169	0.279	0.161	0.261	0.189	0.192	0.222	0.217
C3	0.099	0.069	0.115	0.169	0.186	0.268	0.217	0.135	0.192	0.158	0.161
C4	0.060	0.041	0.023	0.034	0.031	0.018	0.043	0.054	0.013	0.011	0.033
C5	0.099	0.069	0.057	0.102	0.093	0.161	0.087	0.135	0.192	0.158	0.115
C6	0.099	0.069	0.023	0.102	0.031	0.054	0.043	0.027	0.038	0.032	0.052
C7	0.050	0.034	0.023	0.034	0.046	0.054	0.043	0.081	0.115	0.095	0.058
C8	0.043	0.029	0.023	0.017	0.019	0.054	0.014	0.027	0.010	0.008	0.024
C9	0.060	0.041	0.023	0.102	0.019	0.054	0.014	0.054	0.038	0.063	0.047
C10	0.043	0.029	0.023	0.102	0.019	0.018	0.014	0.108	0.019	0.032	0.041
	0.253	0.217	0.161	0.033	0.115	0.052	0.058	0.024	0.047	0.041	
	5.0	4.3	3.2	0.6	2.3	1.0	1.1	0.5	0.9	0.8	
	5	4	3	1	2	1	1	1	1	1	

The criterion 'Originality / novelty of a solution' has the maximum rank (weight 0.253). The criterion 'Character of an innovation has the weight of 0.217 and the criterion 'Scientific verification of a solution' – 0.161.
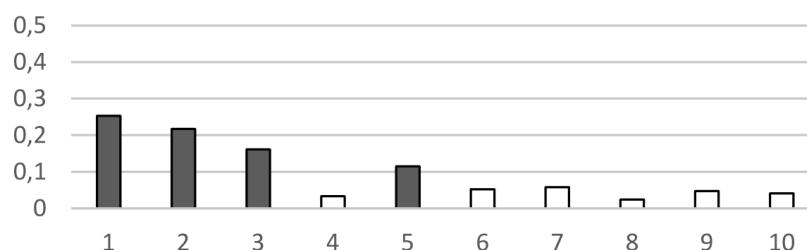

Fig. 2. Comparison of criteria weights
Source: Authors.

The use of the AHP method for the hierarchization of the criteria revealed that some of the criteria had very low weights (in white colour in Figure 2). It means that only four criteria are very significant for the indication of the innovativeness level of the technological product (1 – originality / novelty of a solution, 2 – character of an innovation, 3 – scientific verification of a solution, 5 – practical verification of a solution).

3. An empirical application of the assessment method

The developed hierarchical set of criteria was applied in the innovativeness level assessment method of technological solutions, which are the results of the *'Innovative Systems of Technical Support for Sustainable Development of Economy'* strategic research programme. The assessment of the technological solution is conducted with the use of the IT system [12, 13], which enables

automatic calculation of the final score of the assessment according to the dependency presented in Equation 3.

The AHP method was successfully applied for the assessment of the innovativeness level of the solutions in the *'Innovative Systems of Technical Support for Sustainable Development of Economy'* Strategic Programme. In the assessment process, a determined set of criteria was used. The developed procedure of assessment was very useful for the ranking of ca. 170 technological solutions.

Conclusions

During the development of the method of the innovativeness level assessment, ten (10) criteria were identified. The AHP method helped to establish weights for the criteria.

The authors confirmed the usability of the AHP method as a research tool enabling the verification of the assessment results as the identification of the coherence of the assessment results achieved was helpful in eliminating mistakes and contradictions in partial assessments.

Further research on the improvement of the method of innovativeness level assessment of technological solutions aims at the development of the IT system, which will automate the assessment.

Scientific work executed within the Strategic Programme 'Innovative Systems of Technical Support for Sustainable Development of Economy' within Innovative Economy Operational Programme.

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Dobór kryteriów w metodzie oceny poziomu innowacyjności rozwiązań technologicznych

Słowa kluczowe

Rozwiązanie innowacyjne, ocena poziomu innowacyjności, kryteria oceny, metoda AHP.

Streszczenie

W artykule zaprezentowano metodę hierarchicznej analizy problemu (*Analytic Hierarchy Process* – AHP) w zastosowaniu do opracowania metody oceny poziomu innowacyjności (PI) rozwiązań technologicznych, w tym opracowanych w ramach Programu Strategicznego pn. „Innowacyjne systemy wspomagania technicznego zrównoważonego rozwoju gospodarki" (w zakresie wyznaczania wag obszarów problemowych oraz poszczególnych kryteriów w ramach obszarów). Metoda AHP jest dedykowana głównie do wspomagania wyboru wariantów decyzyjnych, ale również do dokonywania oceny diagnostycznej lub porównawczej w ujęciu wielokryterialnym, szczególnie w przypadku występowania kryteriów jakościowych oraz subiektywnym charakterze dokonywanych przez ekspertów ocen.

Opracowana metoda oceny poziomu innowacyjności (PI) stanowi istotny element wspomagania procesów transformacji wiedzy i transferu zaawansowa-

nych technologii procesowych i produktowych w obszarze wytwarzania oraz eksploatacji maszyn i urządzeń technicznych. Wykorzystanie metody do oceny powstających rozwiązań przyczynia się do wzrostu konkurencyjności gospodarki poprzez zwiększenie efektywności i skuteczności procesu komercjalizacji innowacji.