Marcin MATUSZNY[1]* ORCID: 0000-0002-4124-7355; **Julia STRĄCZEK**[1]

[1] University of Bielsko-Biala, Faculty of Mechanical Engineering and Computer Science, Department of Production Engineering, Poland

* Corresponding author e-mail: mmatuszny@ubb.edu.pl

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APPROACHES OF THE CONCORDANCE COEFFICIENT IN ASSESSING THE DEGREE OF SUBJECTIVITY OF EXPERT ASSESSMENTS IN TECHNOLOGY SELECTION PROCESS

WYKORZYSTANIE WSPÓŁCZYNNIKA ZGODNOŚCI W OCENIE STOPNIA SUBIEKTYWNOŚCI OCEN EKSPERTÓW W PROCESIE DOBORU TECHNOLOGII

Summary: *The article aims to present the issue of assessing the subjectivity of tests in methods used in the technology selection process. The analysis of selecting technology was based on Kendall's concordance coefficient, with more than two experts participating in the study. The selection methods analyzed in the article are comparative (equivalent and weighted) based on the results of the comparative cost calculation method. The main result of the research was to examine the level of agreement among expert evaluations in the inspected technology selection methods. Using Kendall's coefficient of concordance allows for an effective determination of the correctness of technology selection and the implementation of appropriate actions depending on the obtained result. The technology selection process refers to the systematic approach used to evaluate and choose the most suitable technology for a specific task or project. It involves comparing different technologies based on predefined criteria, such as cost, efficiency, and compatibility, to ensure the best possible decision is made.*

Keywords: *technology selection methods, concordance coefficient, ranks, experts opinion*

Streszczenie: *Artykuł ma na celu przedstawienie zagadnienia oceny subiektywności testów w metodach stosowanych w procesie doboru technologii. Analiza doboru technologii została oparta na współczynniku zgodności Kendalla, przy udziale trzech ekspertów. Analizowane w artykule metody doboru są porównawcze (równoważne i ważone) w oparciu o wyniki komparatywnej metody kalkulacji kosztów. Głównym celem badań było zbadanie poziomu zgodności ocen ekspertów w badanych metodach doboru technologii. Zastosowanie współczynnika zgodności Kendalla pozwala na skuteczne ustalenie poprawności doboru technologii i wdrożenie odpowiednich działań w zależności od uzyskanego wyniku. Proces doboru technologii odnosi się do systematycznego podejścia stosowanego do oceny i wyboru najbardziej odpowiedniej technologii do konkretnego zadania lub projektu. Polega on na porównywaniu różnych technologii w oparciu o wstępnie zdefiniowane kryteria, takie jak koszt, wydajność i kompatybilność, w celu zapewnienia podjęcia najlepszej możliwej decyzji.*

Słowa kluczowe: *metody doboru technologii, współczynnik zgodności, rangi, opinia ekspertów*

Introduction

The study of the degree of subjectivity of expert assessments is used in many scientific considerations [1, 2, 3], from works in the field of management and quality to studies in technical sciences, which will be cited later in the considerations. If the phenomenon of ranking occurs in a given analysis, the assessment is made using relatively simple measures – Spearman's rank correlation coefficient ρ or Kendall's rank correlation coefficient τ. In this case, the analysis is focused on the application of Kendall's concordance coefficient, which measures the degree of agreement between the evaluations of multiple experts. This statistical method was chosen as the key tool for evaluating the consistency of expert opinions in the technology selection process.

An example of the use of the above-mentioned coefficients is the assessment of expert opinions for the purposes of foresight research [4]. The aim of this study is to construct scenarios of the development of the situation in the long term (20–25 years), developed by groups of experts using the Delphi method and brainstorming. The ambiguity of experts' answers makes it impossible to make final judgments. The key application here is to examine the subjectivity of expert assessments and to determine the limit values of consistent measures.

Another example is a study conducted to determine the impact of the knowledge-based economy on the functioning of Polish enterprises [5]. Based on a set of criteria, a group of research and teaching staff assessed the significance of the given criteria in terms of the impact of the KBE on the enterprise. The test results are summarized in the table. After calculating the concordance coefficient, the obtained value was compared with the average of Pearson's linear correlation coefficients (r_{av}). The difference between r_{av} and ρ_{av} turned out to be insignificant, which allowed us to draw final conclusions [6].

One of the key factors in effective management of Municipal Solid Waste (MSW) is the selection of appropriate technology, which is a complex, multi-criteria, and labor-intensive process. Despite the global emphasis on the importance of MSW in the literature, there is a lack of research conducted in developing countries that effectively identify and analyze critical performance criteria for the appropriate technology selection. Mehedi Hasan Shanta, Imtiaz Ahmed Choudhury, and Sheak Salman conducted studies aimed at addressing this gap by identifying and prioritizing selection criteria, as well as examining the interrelationships between them and the extent to which they mutually influence each other [7].

In the field of quality management in enterprises, the effectiveness of tools, methods and techniques is also examined by determining the concordance coefficient of experts participating in the research. The scientific study "The effectiveness of quality management tools, methods and techniques in the metalworking industry – expert research" presents a selection of experts who analyzed the usefulness of selected methods, tools and techniques in the metalworking industry. Based on the ranking of the usefulness of the selected instruments, the correlation coefficient of expert assessments was determined, which allowed for drawing clear and final conclusions in the study [8].

A new algorithm for reconstructing wave spectra for sea states with short crests in the frequency domain, based on the analogy of a wave buoy and the Spearman rank correlation coefficient, was investigated in their work by V. Piscopo, S. Ascione, and A. Scamardella [9].

The development of measurement tools based on the classic procedure proposed by G. A. Churchill (1979) [10] involves the help of external experts due to the high subjectivity factor in the selection of preliminary questions for the survey based on qualitative literature. The selection of judges and their number may also be subjective due to the lack of a criterion for selecting judges in the available literature. The multiple ordering coefficient - Kendall's τ correlation coefficient - is used as an indicator for assessing judges' preferences in the selection of parameters of measurement tools of the management system. However, it only applies when judges use the ranking method, which will allow for a comprehensive examination.

Behrouz Arabi, Mehdi Toloo, Zaoli Yang, Peihao Zhang, and Bing Xu proposed an innovative multi-criteria decision-making (MCDM) framework in their research. This framework aims to select cooling technologies that are both carbon and energy efficient, in line with the UK's net-zero emissions policy and the UN's Sustainable Development Goals (SDGs) [11].

Despite advancements in plastic waste recycling technologies, global plastic waste recycling rates remain disappointing. This issue not only suggests the underutilization of existing recycling technologies but also hinders resource utilization, the circular economy, and sustainable production. Several studies have proposed addressing this problem by evaluating recycling technologies based on the quantity of waste recycled. However, such single-indicator methods often overlook other critical factors and may not provide a holistic assessment. Additionally, existing methods for assessing or comparing different recycling technologies are often complex and time-consuming [12].

Background of analysis

In the times of the fourth industrial revolution, investments and technology development became the driving force of economic growth. The introduction of advanced digital technologies into production processes allowed for increased efficiency and autonomy. Developing countries engage in technology transfer to benefit from introducing a well-functioning and efficient production process into the economy. The process of technology transfer to a given economic sector in a given country requires carrying out a number of technology assessment methods, which are exposed to a certain degree of subjectivity by selected groups of experts [13].

F.T.S. Chan, M.H. Chan, and N.K.H. Tang also examine the evolution of technology selection methods in their research. They present an algorithm for technology selection that quantitatively determines both tangible and intangible benefits in a fuzzy environment. Their study describes the application of fuzzy set theory to hierarchical structural analysis and economic evaluations [14].

The issue of transferring appropriate technology to the target country is the consequence of the life cycle of products and technologies on the correct assessment in the transfer process [15].

G. Grünert, T. Grünebaum, A. Beckers, L. Stauder, S. Barth, and T. Bergs developed an economic-ecological key performance indicator that integrates production costs, material flow costs, and environmental impact, as determined through life cycle assessment, to provide a holistic perspective [16].

Moutaz Khouja proposed a decision model for technology selection problems, utilizing a two-phase procedure in his research [17].

Nancy T. Tippins discussed how technological advancements challenge testers and evaluators with fundamental changes in assumptions about best testing practices. Her research addresses issues such as distraction, changes in the candidate pool, cheating, and their impact on test outcomes [18].

Miao-Yu Tsai and Chao-Chun Lin proposed an alternative analysis method based on variance components (VC). This approach allows for dependency between repeated measurements over time to evaluate internal consistency for each observer, agreement between observers, and overall agreement among multiple observers simultaneously within the framework of extended three-way generalized linear mixed models (GLMM) for both normal and Poisson data [19].

Most of the technologies involved in the technology transfer process come from highly industrialized countries, which are adapted to the market of their country of origin. These will be technologies recognized as mature technologies that reflect the capabilities of mass production as well as the efficiency of a well-developed industrial infrastructure. Using technology over a longer period of time allows for larger or smaller corrections

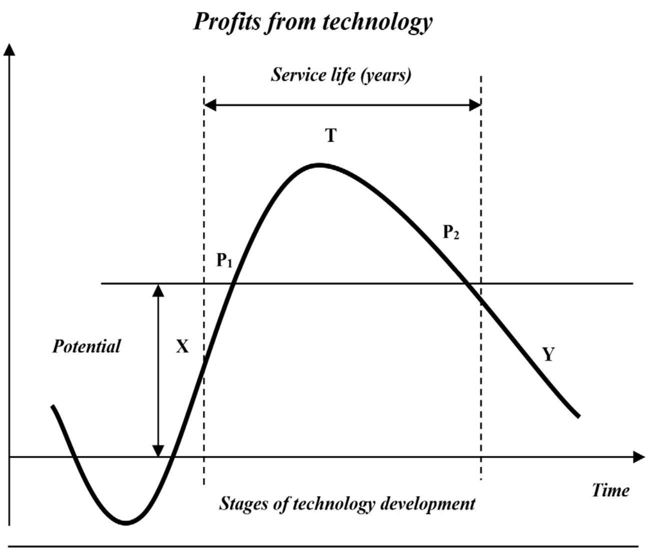

Fig. 1. Technology life cycle
Source: own elaboration

and protects it legally in accordance with the regulations of the environment in which it operates.

Marko Torkkeli and Markku Tuominen conducted research on understanding the links between technology selection and a company's core competencies. [reference] Shuang Ma, Linda L. Zhang, and Xiaotian Cai focused on analyzing the alignment of decision-making between a manufacturer and its independent supplier [20].

Research analysis

The issuance of a general judgment based on expert assessments requires a compliance assessment. Noting discrepancies in assessments does not authorize us to perform such operations. In the event of non-compliance, consider what further action is appropriate.

The lack of consistency in assessments on a given topic may be caused by three sources. The first reason for the lack of consistency of opinions is the lack of competence of the group of evaluators, which may have been poorly selected for a given evaluation process. The second reason is an incorrectly defined evaluation object. The third reason is an improperly organized evaluation process [21]. Ashok Kumar J and Abirami S explored opinion mining, also known as sentiment analysis, in their work [22].

Identifying the lack of compliance in expert assessments allows you to eliminate the sources of inconsistency or refrain from issuing a final assessment about the examined object. Marie-Therese Puth, Markus Neuhäuser, and Graeme D. Ruxton investigated the effectiveness of two rank correlation coefficients (Spearman's rho and Kendall's tau) in describing the strength of the relationship between two continuously measured variables. In their work, Bin Wang, Ruodu Wang, and Yuming Wang followed up on the equivalence of the Spearman's rho matrix and the linear correlation matrix for dimensions up to 9, as shown in the literature. They demonstrated, however, a lack of equivalence for dimensions of 12 and higher [23].

In order to conduct the main analysis of the use of the concordance coefficient in the technology selection process, the essence of measuring the compliance with Kendall's correlation coefficient τ in strong rankings and in the case of tied ranks will be presented.

Essam F. El-Hashash and Raga Hassan Ali Shiekh present the correct use of correlation coefficient in research methodology as the most frequently used statistical measure [24]. Weichao Xu, Yunhe Hou, Y.S. Hung, and Yuexian Zou examined the differences between Spearman's and Kendall's correlation coefficients [25].

Measuring the consistency of strong rankings

Important factors in the process of assessing expert agreement are the number of preferential series and the type of ordinal scale. The preferential series reflects the ordering of a set of elements made by a given expert, and the ordinal scale is the position of given objects in relation to others, determined on the basis of the assigned rank. The type of ordinal scale (strong or weak) influences the selection of the significance test and the course of calculations.

When examining orderings between two series, Spearman's ρ rank correlation coefficient is used. In their article, Michael Stephanou and Melvin Varughese describe a new sequential estimator of Spearman's rank correlation coefficient based on Hermite series, and present algorithms applicable in both stationary and non-stationary settings [26]. Due to the fact that there are more preferential series in the technology assessment process, the study will be carried out using Kendall's W concordance index, i.e. the coefficient of concordance of multiple orderings. Przemysław Grzegorzewski proposed a new

Table 1. Example of three strong preference series

Specification	A	B	C	D	E	F	Sum of ranks
expert 1	3	1	4	2	5	6	**21**
expert 2	2	3	5	1	6	4	**21**
expert 3	3	2	6	1	5	4	**21**
Sum of ranks R_j	**8**	**6**	**15**	**4**	**16**	**14**	**63**

Source: own elaboration

measure of concordance that generalizes Kendall's coefficient. The suggested coefficient can be applied in situations with missing information or incomparable outcomes [27].

Measuring the consistency of assessments comes down to the construction of a coefficient whose numerator reflects the actual connections between the preferential series (S) and the denominator is the maximum value that can be obtained in a situation of full consistency of assessments (Smax).

After assessing n objects by m observers, an ordering matrix is obtained. The columns present the ranks assigned to objects by experts, and the rows present preferential ranks.

A characteristic feature of strong ranking is that all the ratings given to objects by one expert are different. Hervé Abdi also discussed an example of ranking strength and its correlation coefficient in his work [28]. The consequence is that a given expert is able to arrange (rank) the examined objects in order of importance. If all ranks have a strong order, we can write the sum of ranks $\frac{mn(n+1)}{2}$, and the arithmetic mean of the rank sums $\frac{m(n+1)}{2}$. Formulas necessary for further calculations:

1) sum of ranks for R_j for *j*-th object:

$$R_j = \sum_{i=1}^{m} a_{ij} = \frac{n(n+1)}{2} \qquad (1)$$

2) the sum of the rank sums of all *n* objects:

$$\sum_{j=1}^{m} R_j = \frac{mn(n+1)}{2} \qquad (2)$$

3) arithmetic mean of rank sums for all *n* objects:

$$R = \frac{1}{n}\sum_{j=1}^{n} R_j = \frac{m(n+1)}{2} \, [29] \qquad (3)$$

4) sum of squared deviations R_j from the mean R [30]:

$$S = \sum_{j=1}^{n}(R_j - R) = \sum_{j=1}^{n}(R_j - \frac{m(n+1)}{2})^2 \qquad (4)$$

5) maximum value of the sum of squares of deviations R_j from the mean R (full agreement of ranks between preferential series):

$$S_{max} = \sum_{j=1}^{n}(jm - \frac{m(n+1)}{2})^2 = m^2 \sum_{j=1}^{n}(j^2 - 2j\frac{(n+1)}{2} + \frac{(n+1)^2}{4}) \qquad (5)$$

And transforming the formula for the sum of the squares of the n first natural numbers:

$$S_{max} = m^2(\frac{n(n+1)(2n+1)}{6} - \frac{n(n+1)^2}{2} + \frac{n(n+1)^2}{4}) = \frac{m^2(n^3-n)}{12} \qquad (6)$$

The compliance factor in the final representation is the quotient of the quantities S and S_{max}:

$$W = \frac{S}{S_{max}} = \frac{\sum_{j=1}^{n}(R_j - \frac{m(n+1)}{2})^2}{\frac{1}{12}m^2(n^3-n)} \qquad (7)$$

Measuring the consistency

Weak ranking occurs when related ranks appear, which means that experts assigned the same ranks to some objects. Therefore, one (or more) rank binds two or more objects. The occurrence of weak sequencing can be observed in two cases:

1) n objects are assessed on a scale from 1 to n. Observers are unable to notice differences between some objects and therefore give them the same rank,
2) n objects are assessed on a scale from 1 to k, but k is a natural number smaller than n. The natural situation is that some objects will receive the same assessment and will be associated with the same rank.

In order to apply the concordance coefficient in the case of weak ranking, it is necessary to use the average rank method. The use of this method allows for averaging the related ranks and obtaining a series analogous to strong ranking, where the sum of the ranks is equal to $\frac{n(n+1)}{2}$.

As you can see in the table, objects D and E and C and F have been associated with the same rank. To average repeated ranks, a simple operation should be performed. For object D and E it will be this $\frac{(2+3)}{2} = 2{,}5$ (the digit 2 takes the second and third position in the order), while for objects C and F the average rank is $5{,}5$ $(\frac{(5+6)}{2})$. The remaining objects receive ranks according to the order. The result of ranking averaging is a series whose sum is equal to the sum of the first 9 natural numbers, which gives it the characteristics of a strong ranking.

The next step necessary to calculate the concordance coefficient of weak rankings is to introduce a correction in the denominator of the concordance coefficient. The correction value is calculated according to the formula:

$$T_i = \frac{1}{12} \sum_{j=1}^{k}(t_j^3 - t_j) \qquad (8)$$

Table 2. Example of a weakly ordered preferential series with transformation

	A	B	C	D	E	F	G	H	I	Sum of ranks
Expert Rank 1	5	1	4	2	2	4	6	7	3	**34**
Ranks averaged	7	1	5.5	2.5	2.5	5.5	8	9	4	**45**

Source: own elaboration

where k means the number of groups having the same rank in the *i*-th series, and the symbol i.e. the number of identical ranks associated in a given group. According to the example given, the denominator correction will look like this:

$$T_1 = \frac{1}{12}\left((2^3 - 2) + (2^3 - 2)\right) = 1.$$

For m series with tied ranks, the value of T is equal to:

$$T = \sum_{i=1}^{m} T_i. \tag{9}$$

Taking into account the correction of the denominator, the final concordance coefficient for the weak ranking is:

$$W = \frac{S}{S_{max} - mT} = \frac{\sum_{j=1}^{n}\left(R_j - \frac{m(n+1)}{2}\right)^2}{\frac{1}{12}m^2(n^3 - n) - mT}. \tag{10}$$

The *W* coefficient ranges from 0 to 1.

Assessment of the subjectivity of expert assessments

In the process of selecting the appropriate technology, various yarn production systems were compared. The research covered the fine-spun cotton system, the medium-spun cotton system, the worsted wool system, the carded wool system and the converter system. Based on available calculation and comparison methods, the importance of key aspects for the proper operation of a given technology was analyzed. Based on the collected data, an assessment of the subjectivity of the assessments collected from experts participating in individual methods was carried out.

Methods used in the technology selection process – comparative cost calculation method

The comparative cost calculation method allows you to compare implemented technologies in terms of generated costs, efficiency and profits. The factor determining the final result of the method is the ratio of PBT (net profit before tax) to investments in fixed assets. This method will be appropriate when the aspects presented in the table above are similar for the compared technologies, and the situation takes place in a highly developed country, where access to raw materials is not limited and market costs are the decisive criteria. However, in developing countries, additional factors need to be taken into account. For example, restrictions on foreign trade may be a key factor in the selection of technologies, preferring those that use domestic capital resources or raw materials. Additionally, restrictions on the availability of natural resources may encourage decision-makers to choose technologies based on alternative energy sources, such as hydroelectricity instead of petroleum fuels. In such conditions, the person deciding on the choice of technology may be ready to accept higher costs and lower economic efficiency in exchange for minimizing the use of scarce raw materials. It should also be noted that the comparative cost method has certain limitations. First of all, it does not take into account qualitative aspects. To address these elements, alternative methods such as parameter comparisons and scoring systems are used. The results obtained in the above table will be used for further methods.

Comparison methods involve comparing different options or solutions in order to select the best or most appropriate technological system, e.g. taking into account the limitations in a given country. There are two main categories of rollup methods: equivalent rollups and weighted rollups.

Depending on the analyzed technologies, the criteria for selecting key parameters from the comparative costing method may be different. The table below presents an example of a comparative cost calculation method, on the basis of which the comparison method will be carried out. Technology A – fine-spun cotton system, technology B – medium-spun cotton system, technology C – worsted wool system, technology D – carded wool system, technology E – converter system.

Table 3. Comparative cost calculation method (in millions of EURO)

	Technology				
	A	**B**	**C**	**D**	**E**
Annual sales value of the product	18	18	18	18	18
Investments in fixed assets foreign currency national currency total	 4.2 5.8 10.0	 3.9 7.5 11.4	 3.5 6.2 9.7	 6.0 5.9 11.9	 4.5 8.0 12.5
Raw materials and auxiliary materials local imported total	 0.8 1.4 2.2	 0.8 1.7 2.5	 1.8 0.6 2.4	 1.2 1.1 2.3	 0.5 2.1 2.6
Fuels petroleum derivatives electricity total	 0.5 2.1 2.6	 0.4 1.9 2.3	 0.5 1.5 2.0	 0.6 1.2 1.8	 0.7 2.2 2.9
Workforce semi-skilled highly qualified total	 0.3 0.6 0.9	 0.4 0.3 0.7	 0.4 0.5 0.9	 0.6 0.2 0.8	 0.6 0.8 1.4
General operating costs	5.7	5.5	5.3	4.9	6.9
Training costs	0.7	0.5	0.7	0.5	0.9
Maintenance costs	0.6	0.4	0.6	0.4	0.5
Plant and project overhead costs	4.0	4.0	4.0	4.0	4.0
Cost of operating capital	0.33	0.28	0.39	0.26	0.29
Amortization (10 years)	0.97	1.01	0.85	0.95	1.10
Technology costs Single fee Number of installments Installment interest rates Installment repayment period	 0.80 1 - -	 0.20 1 3 5	 - - 6.5 3	 1.11 3 - -	 0.22 1 6 6
Total cost of technology	0.80	1.95	2.44	0.93	3.62
Annual technology cost	0.16	0.39	0.49	0.19	0.72
Annual production cost	12.46	12.08	12.33	11.20	14.41
Profit before tax (PBT)	5.54	5.92	5.67	6.80	3.59
PBT/investments in fixed assets (%)	55.4	51.9	58.5	57.2	28.7

Source: own elaboration

The table presents sample results of the analysis of a given group of experts responsible for examining the financial parameters of a given technology. The calculation and selection of individual components is not the subject of this article. The essence is to submit the collected data to summary methods.

Methods used in the technology selection process – summary methods

Comparison methods involve comparing different options or solutions in order to select the best or most appropriate technological system, e.g. taking into account the limitations in a given country. There are two main categories of rollup methods: equivalent rollups and weighted rollups.

The equivalent ranking is the simplest method - the analyzed technologies receive points for effectiveness, the highest score for best meeting the conditions of each parameter, e.g. maximizing profits from domestic investments or minimizing fuel gas consumption. The following analysis established five criteria:

- Investments in fixed assets in national currency are optimized,
- Reducing gas consumption,
- Reducing the costs of imported raw materials,
- Reducing electricity consumption,
- minimizing the need for highly qualified labor.

The criteria are selected by the next expert group, which will influence the result of further analysis. The table below shows an example of the parameters selected above for the tested technologies.

Table 4. List of technology parameters (equivalent)

Parameter	Technologies				
	A	B	C	D	E
Investments in national currency	5	2	3	4	1
Imported raw materials	3	2	5	4	1
Fuel gas	3	4	3	2	1
Electricity	2	3	4	5	1
Skilled labor	2	4	3	5	1
Sum	**15**	**15**	**18**	**20**	**5**

Source: own elaboration

Table 5. Weights of the parameters of the weighted summary

Parameter	Weight
Imported raw materials	0.35
Electricity	0.21
Permanent investments in national currency	0.19
Skilled labor	0.15
Fuel gas	0.1

Source: own elaboration

Another listing method is weighted listing, which is a much more appropriate practice in the context of technology listing. The next expert group or selector (expert) selects the parameter weights and limiting factors on the basis of which the analysis will be carried out. The parameter weights are selected in such a way that their sum does not exceed 1.

In order to correctly calculate the parameter value, perform calculations as follows:

$$\textit{Weighted rating} = \frac{\textit{Evaluation of the parameter in a given technological process}}{\textit{Highest rating assigned to any technology in this parameter}}\ x\ \textit{weight parameter}$$

Example:
Parameter: imported raw materials – weight 0.35
Parameter rating for fine-spun cotton system technology: 3
The highest parameter rating for technology: 5

The above calculations are performed for each parameter and each technology in accordance with the assigned weights.

$$\textit{Weighted rating} = \frac{3}{5}\ x\ 0.35 = 0.21$$

Table 6. Weighted list of technologies

Parameter	Technologies				
	A	B	C	D	E
Investments in national currency	0.19	0.076	0.114	0.152	0.038
Imported raw materials	0.21	0.14	0.35	0.28	0.07
Fuel gas	0.075	0.1	0.075	0.05	0.025
Electricity	0.084	0.126	0.168	0.21	0.042
Skilled labor	0.06	0.12	0.09	0.15	0.03
Weighted rating	**0.619**	**0.562**	**0.797**	**0.842**	**0.205**

Source: own elaboration

A point system method is an assessment or management method in which points are assigned to specific elements, aspects or activities in order to evaluate or compare them. In the context of introducing new technology into an enterprise, the point system method can be used to evaluate various factors related to technology implementation.

For example, a company can create a set of criteria such as effectiveness, efficiency, cost, data security, etc., and assign points to each of these criteria. Points are then allocated based on the technology's performance in each of these areas. The total score can be used to assess the overall suitability and success of implementing a new technology.

Conducting an analysis using the point system method requires a group of experts to define key evaluation criteria, determine basic parameters and assign them weights. Then, a reference technology is selected, which serves as a reference point for assessing other technologies. An example of the point system method used is included in the table below.

Table 7. Point system method

Parameter	Technologies					
	Scoring system scale	Reference technology	A	B	C	E
Machine parameters Reliability Price Cycle time Availability of spare parts Dimensions	100 90 80 70 70	90 90 80 60 65	80 70 60 55 50	95 80 75 60 60	85 75 65 65 55	75 80 75 55 70
Product parameters Resilience	80	75	65	70	70	65
Wear Main drums Carding machines	60 60	60 50	50 45	55 55	45 50	50 45
Security Cutting converters Dust Coloring chemicals	50 40 35	40 35 25	15 40 35	30 30 35	40 30 25	20 35 30
Environmental factors CO_2 emissions Microplastics	30 20	25 15	25 20	30 15	15 20	20 10
Technology adoption Time	40	35	30	35	25	30
Sum	**825**	**745**	**640**	**725**	**665**	**660**

Source: own elaboration

Assumptions – a summary of expert assessments

Due to different groups of experts, each of the above methods is characterized by a certain degree of subjectivity in the selection of parameters and the assignment of ratings. The high consistency of the assessments selected by each group of experts allows for further conclusions to be drawn as to whether a given technology is appropriate. The recorded discrepancy between expert assessments does not authorize us to perform such operations. Due to the analysis of the assessments of three expert groups, the study will use W. Kendall's concordance coefficient, which works well for examining the consistency of multiple rankings. The first research phase will be based on compiling all assessments of the methods performed and assigning them appropriate ranks that will enable further calculations to be carried out. The second phase is the classification of the resulting rankings and division into weak and strong rankings, which will allow for the correct selection of further calculations and averaging of ranks in the case of weak rankings. The third phase is the calculation of the concordance index for the analyzed methods and the submission of dehydrated conclusions to the obtained results. The tables below present the results of the methods performed, along with the assignment of ranks and their average in the case of combined ranks. Rank averaging was performed according to the formula given in the theoretical part regarding the subjectivity of tests $(\frac{n(n+1)}{2})$. Due to the analysis of five technologies related to yarn production, the ranks were assigned in the range from 1-5.

Table 8. Results of the equivalent ranking method along with assigning ranks

Equivalent statement	A	B	C	D	E	Sum of ranks
Results	15	15	18	20	5	
Assigning ranks	2	2	3	4	1	12
Ranks averaged	2.5	2.5	4	5	1	15

Source: own elaboration

Table 9. Results of the weighted ranking method along with assigning ranks

Weighted summary	A	B	C	D	E	Sum of ranks
Results	0.619	0.562	0.797	0.842	0.205	
Assigning ranks	3	2	4	5	1	15

Source: own elaboration

Table 10. Results of the point system method along with assigning ranks

Point system method	A	B	C	D	E	Sum of ranks
Results	640	725	665	745	660	
Assigning ranks	1	4	3	5	2	15

Source: own elaboration

Calculations

Table 11. List of expert ranks

	A	B	C	D	E	T_i
Expert Rank I	2.5	2.5	4	5	1	21
Expert Rank II	3	2	4	5	1	
Expert Rank III	1	4	3	5	2	
R_j – Sum of ranks	**6.5**	**8.5**	**11**	**15**	**4**	

Source: own elaboration

The last row of table 11 gives the sum of ranks for individual technologies (R_j) and the last column shows *Ti*, i.e. the correction for combined ranks (*T*, formula 8). The total value of *T* in the ranking will be equal to T_1, due to the occurrence of only one weak ranking with tied ranks. The sum of the squares of deviations R_j from the mean $R = \frac{m(n+1)}{2}$ (i.e. S) is 72. In the next step, the maximum value of the sum of squares of deviations R_j from the mean *R* should be calculated, i.e. for the situation of full correspondence of ranks between the preferential series (*m* – 3 experts, *n* – 5 analyzed technologies):

$$S_{max} = \frac{m^2(n^3-n)}{12} = \frac{3^2(5^3-5)}{12} = 90.$$

The data prepared in this way allows for the calculation of the concordance coefficient (formula 10). Due to the occurrence of one series with linked ranks, the coefficient should be calculated by adjusting the denominator:

$$W = \frac{S}{S_{max}-mT} = \frac{72}{90-3\cdot 0.5} = 0.81.$$

As a result of the calculations, a concordance coefficient of 0.81 was obtained. This means high consistency of expert assessments in the three analyzed technology assessment methods. The high compliance rate allows us to conduct further analysis in terms of selecting the right technology in the process of implementing technology into the new environment.

Conclusions

The selection of appropriate calculation methods as well as appropriate groups of experts in the technology selection process is important for a complete overview of the analyzed technologies. The use of the subjectivity coefficient allows for verification of the competences of the assessment group or analysis of the assessment carried out in terms of correctness or structure. Obtaining high consistency of expert assessments allows for the formulation of final conclusions and the selection of the technology that, based on the methods performed, turned out to be the most suitable for implementation in the new environment. However, the key question is what to do in the case of a low Kendall's concordance coefficient. The first step may be to check the evaluation groups and how the evaluation was carried out. However, the following question arises. What should be done when a change of expert groups and a more precise implementation of the presented technology selection methods result in slight differences in the obtained results and the concordance coefficient is low? It is worth considering whether assigning ranks to n objects on a scale from 1 to n will always be an appropriate method to determine the compliance coefficient. Do the grades obtained, e.g. in the point system method, entitle you to assign ranks in the same way as in other methods, where the grades are determined in a different numerical range (e.g. a weighted ranking). Would it be more appropriate to rank n objects on a scale from 1 to k? It is also worth considering the method of selecting the scoring scale and the selection of parameters, which will have a direct impact on the final ratings, which will contribute to changing the value of the consistency coefficient of expert assessments.

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