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The use of rank and optimisation methods in strategic management in higher education

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Abstract

The article presents proposals for a university management model supporting the process of strategic management at a university. The proposed model is based on the use of multi-criteria methods such as the 0–10 technique, object ranking, and optimisation methods – linear programming. The proposed solution integrates ranking and optimisation methods, the use of which may be helpful in the hands of managers in making management decisions. The proposed approach may also be helpful in developing a strategic scorecard, especially in the stage of formulating goals. It also enables the optimal selection of goals with the existing time constraints for the implementation of the strategy. The article presents a proposal for the use of the strategy implementation model and an example of its use. The strengths and weaknesses of the model were also indicated.

Keywords: *higher education institution, strategic management, strategy implementation, linear programming*

1. Introduction

Universities, both public and private, operate in an extremely turbulent environment. The ability to adapt to the changing environment, meet the growing expectations of university stakeholders, and compete for students, staff, and financial resources requires the search for new, effective solutions. The functioning of educational services in the competitive market is not only about providing the highest quality services or conducting scientific research. Modern universities are also expected to consider and meet the numerous needs of their stakeholders, including students, employees, management, employers, and society. In the case of higher education, the aspect of progressing European integration or the impact of the knowledge-based economy is also important. The assumptions of the state's science, technology, and innovation policy include the following statement: *It is necessary to change the science management*

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system and bring it closer to managerial management based on rational planning, methods, and techniques of strategic management and training in this field of personnel [15]. The current management of universities is far from that presented in the assumptions. A significant number of universities in Poland do not use a managerial approach to management [17], and each proposal to improve the current situation seems useful and important [19]. What is particularly important, in the process of planning, formulating, implementing, or controlling and monitoring the strategy implementation process, it is necessary to take into account the specificity of the functioning of the university as an organisation whose goals are closely related to the social mission being implemented. There is a well-known statement: *Even the greatest strategies are not very useful if we are unable to implement them* [16]. It is indicated that the strategy implementation process fails in 50–90% of organisations [12]. Other sources say that no more than 50% of planned strategies can be implemented [9]. Hrebiniak points out that the contribution to the formulation of the strategy is much greater than its implementation [10]. On the other hand, ater and Puko emphasise that although 80% of organisations have appropriate strategies, only 14% manage to implement them [4].

As has been repeatedly indicated in numerous research works [3] and supported by empirical studies, [14, 18] such a solution is undoubtedly the replacement of traditional management with strategic management at universities [6]. It is also emphasized that strategic management is becoming one of the most promising mechanisms for the development of higher education in difficult and unpredictable conditions [21]. It should be noted, however, that although such an approach has been known for decades, strategic management at universities still poses many problems to be solved. Therefore, it is important to search for effective methods and tools supporting the strategic management process at universities. Alexander emphasizes that the problem of effective strategy implementation lies in its implementation by employees [1]. Despite the multitude of studies of a cognitive and empirical nature, a research gap can be observed in the presented area. This is due to the lack of a comprehensive tool supporting the university's strategic management process and facilitating strategic decision-making. There is no tool that would allow for the optimal indication of what strategic goals should be pursued, bearing in mind the greatest satisfaction of the university's stakeholders and the existing limitations. Of course, Kaplan and Norton's strategic scorecard is known. The literature on the subject is rich in works presenting examples of the use of BSC in the process of higher education management [8, 13]. The authors also point out that although this tool has been known in the business for decades, its implementation at universities is still not easy, and the strategic management process itself still requires repair. The model proposed may support the development of a strategic scorecard at the stage of formulating and selecting strategic goals under the BSC perspectives.

So far lacks a proposal to use object-oriented ranking in the decision-making process at universities. Therefore, the aim of the article is to propose a higher education management model supporting the process of strategic management in a university. The proposed solution is the integration of ranking methods (object-oriented ranking, the 0–10 technique) and optimisation methods (linear programming), the use of which may be helpful in making management decisions, in particular, in the development of a strategic scorecard at the stage of formulating and selecting strategic goals. The first chapter presents an introduction to the topic and the research gap. The second one is a literature review of the issues presented. In the next section, the author's model of implementation has been presented.

2. Literature review

2.1. Linear programming. Basic information

Linear programming (LP) is used when a decision problem arises. Considering that the decision-maker may face difficulties due to the proper choice of different options. It is therefore reasonable to make a decision in the best way, taking into account the existing constraints.

Linear programming allows one to solve specific decision problems in an optimal way. The essential LP is the formulation of the decision problem in the form of a mathematical model. The mathematical model is formulated in the form of determining the function of the goal that the decision-maker intends to achieve and the constraints resulting from the fact that the organisation usually has a certain amount of resources at its disposal.

The objective function in the mathematical model takes a linear form and the set of constraining conditions is represented by linear equations and inequalities. The objective function f takes the form:

$$f = \alpha + c_1x_1 + c_2x_2 + \cdots + c_nx_n, \quad \text{where} \quad x_1 \geq 0, \quad x_2 \geq 0, \ldots, x_n \geq 0 \tag{1}$$

In the case of a maximising, minimising criterion function, the limiting conditions assumed by the decision variables x_i take the form:

$$\sum_{j=1}^{n} a_{ij}x_j \leq (\geq, =)b_i \quad \text{for} \quad i = 1, \ldots, n, \quad x_j \geq 0, \quad \text{for} \quad j = 1, \ldots, n \tag{2}$$

Linear models with a single objective function are called single-criteria models. Where the decision-maker wishes to achieve two or more objectives, it requires the construction of multi-criteria models.

2.2. Use of linear programming in higher education

One of the main tasks of university management is the optimisation and continuous improvement of processes taking place at universities. This effect can be achieved only as a result of making the right decisions. Considering the dynamic environment of modern universities, a large amount of information, and the relatively short time for decision-making, this process seems to be extremely difficult. Linear programming is a tool that has proven itself in these difficult conditions. We can also observe that it is increasingly used not only in business [14] but also in universities.

The literature provides many examples of the application of linear programming (LP) to decision-making in higher education. For example, Tadic and Marasovic present the application of linear programming as a tool to support the process of optimising the allocation of human resources in a university [18]. Analogous research in the presented area was also conducted, among others, by Gavrus and Limbasan [7]. Other applications of linear programming in universities present Atanasova-Pacemska and Timovski [2]. In their paper, the authors present the use of PL as a tool to help allocate tangible and intangible resources in order to propose the best possible study programmes. In light of the literature analysis conducted, it should be pointed out that there is a lack of research on linear programming for strategic scorecard (BSC) management in higher education institutions.

According to the above, it can be concluded that the application of linear models in operational research in higher education is very wide. They can be used, among other things, for optimal allocation of human resources, allocation of tangible and intangible resources or evaluation of personnel and determination of appropriate remuneration. According to the authors, they can also be used in university management, in particular in strategic scorecard management. The following part of the article presents proposals for the application of linear programming for the optimal selection of strategic objectives in a university.

2.3. Goal ranking methods

The issue of rankings in management processes is well known. The literature on the subject provides numerous examples of the application of rankings in various disciplines dealing with organisation and management [20]. The authors of this article agree with the opinion of W. Wudarzewski treating that most problems of organisation and management refer directly or indirectly to the issues related to the rank of various components and situational factors [20]. It should be emphasised that the number of examples of research and analysis oriented towards rank and prioritisation is considerable, and the very range of possible situations and themes in the area of organisational management is extremely wide and varied. Among the most important advantages of the presented research methodology, the following are listed: the application of ranks and priorities as an important element of methodological rationality of behaviour, the ordering of activities related to the recognition, analysis and solution of organisational problems, or the facilitation of issues related to the assessment of the actual rationality of conducted activities. The importance of ranks and priorities is also emphasised in situations of multiple factors and high variability of conditions, which is a characteristic feature of the functioning of modern organisations. The literature on the subject provides examples of many ways to rank [20] in management from simple, intuitive and individual to more complex - that is, more methodologically correct. The object rank approach and the 0–10 technique were used in this study.

2.4. Ranking objects in the light of multi-criteria evaluations. Basic information

The literature on the subject provides numerous examples of the application of multi-criteria methods in the decision-making process [18, 20]. Ranking finds its application wherever there is a shortage of resources required to perform certain tasks. Therefore, there is a need to rank objects according to their importance. One of the commonly used methods is object ranking. This tool has been widely used in many fields of science, including management science. Among the advantages of the presented method, the authors point out both its simplicity and usefulness in the decision-making process [20].

The ranking process consists in determining the objects O being the subject of the ranking. The object (objects) of ranking in a higher education institution can be strategic objectives.

$$O = O_1, O_2, \ldots, O_r$$

where r is the number of objects under study.

Each object subject to analysis is a set of diagnostic variables X, which describe the phenomena in the object. In the discussed case the diagnostic variables may be, among others: the cost of implementation of the strategic objective, the time of implementation of the strategic objective, the assessment of access to the resources necessary for the implementation of the strategic objective, or stakeholders' satisfaction (assessment) with the implementation of the strategic objective. Set of diagnostic variables

$$X = X_1, X_2, \ldots, X_s$$

where s is the number of diagnostic variables.

The basis for developing a ranking of strategic objectives is the division of diagnostic variables X into three subsets. The first set called stimulants is a set of such variables whose increase should be identified with an increase, and decrease with a decrease in the assessment of a complex phenomenon. The second set includes destimulants, i.e. such diagnostic variables whose increase should be associated with a decrease in the assessment of the phenomenon under consideration (a decrease, on the other hand, with an increase in the assessment).

The last set of diagnostic variables are nominants. These are variables that have a certain value, the most favourable from the point of view of the assessment of a complex phenomenon. [85] In order to make a multi-criteria evaluation of individual phenomena, it is necessary to transform the values of the original characteristics. This requires a process of normalisation, consisting of the transformation of diagnostic variables, which without changes take on values of a similar order of magnitude [11]. We standardise stimulants based on the formula

$$z_{ij} = \frac{X_{ij} - \min\limits_i x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}} \tag{3}$$

where $i = 1,\ 2,\ 3,\ \ldots,\ r$ and $j = 1, 2, 3,\ \ldots,\ s$.

$$X_j \in S$$

S is a subset of diagnostic variables called stimulants. The stimulants are normalised by using formula

$$z_{ij} = \frac{\max\limits_i x_{ij} - x_{ij}}{\max\limits_i x_{ij} - \min\limits_i x_{ij}} \tag{4}$$

where $i = 1,\ 2,\ 3,\ \ldots,\ r$ and $j = 1, 2, 3,\ \ldots,\ sX_j \in D$

D is a subset of diagnostic variables called destimulants. The nominants are normalized according to the nature that the variables take. If a nominant takes one particular value c_{0j}, we use the formula

$$\begin{cases} \dfrac{x_{ij} - \min\limits_i x_{ij}}{c_{0j} - \min\limits_i x_{ij}} & \text{if } x_{ij} < c_{0j} \\ 1 & \text{if } x_{ij} = c_{0j},\ X_j \in N \\ \dfrac{x_{ij} - \max\limits_i x_{ij}}{c_{0j} - \max\limits_i x_{ij}} & \text{if } x_{ij} > c_{0j} \end{cases} \tag{5}$$

If the nominant is a set of $[C_{1j}, C_{2j}]$ formula should be applied

$$\begin{cases} \dfrac{x_{ij} - \min\limits_i x_{ij}}{c_{1j} - \min\limits_i x_{ij}} & \text{if } x_{ij} < c_{1j} \\ 1 & \text{if } c_{1j} \leq x_{ij} \leq c_{0j},\ X_j \in N \\ \dfrac{x_{ij} - \max\limits_i x_{ij}}{c_{2j} - \max\limits_i x_{ij}} & \text{if } x_{ij} > c_{2j} \end{cases} \tag{6}$$

The method of normalisation presented above is called the zero unitisation method. It allows the assumption of a fixed reference point, in which the interval of the normalised variable is constant and equals 1, while the normals are from the interval $[0, 1]$ [11].

Table 1. Matrix of normalised variables

Object i	Diagnostic variables			
(strategic objective)	x_1	x_2	$\cdots$	x_j
d_1	Z_{11}	Z_{12}	$\cdots$	Z_{1j}
d_2	Z_{21}	Z_{22}	$\cdots$	Z_{2j}
$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$

The result of the normalisation is the matrix shown in Table 1. The development of the ranking requires the determination of aggregate (synthetic) variables based on the formula

$$Q_i = \sum_{j=1}^{s} z_{ij},\ i = 1, 2, 3, \ldots, r \tag{7}$$

where Q_i is a synthetic variable that is a multi-criteria evaluation of a complex phenomenon characterising an ith object. The higher the value of the synthetic variable Q_i, the better the position of a given object in the ranking is. As Kukuła points out, it is also possible to group objects in order to distinguish the best, average, and worst objects [5]. For this purpose, the following formula can be used.

$$U = \frac{\max\limits_i Q_i - \min\limits_i Q_i}{3} \tag{8}$$

resulting in a subgroup of best objects for

$$Q_i \in (\max_i Q_i - U,\ \max_i Q_i]$$

the subgroup of average objects for

$$Q_i \in (\max_i Q_i - 2U,\ \max_i Q_i - U]$$

a subgroup of the worst objects for

$$Q_i \in (\max_i Q_i,\ \max_i Q_i - 2U]$$

2.5. Use of object ranking in the light of multi-criteria evaluation in higher education

Although the object ranking method has found wide application in various fields of science, including organisational management sciences, in the opinion of the authors of this article there is no proposal of object ranking in the decision-making process in higher education institutions. Referring to the commonly proclaimed statements about the poor level of strategic management in contemporary universities and the necessity of taking immediate corrective measures, the search for effective tools facilitating the decision-making process seems justified and even necessary [5, 19]. In a higher education institution grouping strategic objectives into particular subgroups may provide valuable management information. The grouping may indicate on which objectives the management should concentrate its efforts in order to manage the university as effectively as possible. Which goals should be taken for further analysis while developing and then managing the strategic scorecard.

The use of ranking of objects (strategic goals) taking into account multi-criteria evaluations may be one of the basic premises for the right decision-making, [20] which, in consequence, according to the authors of the article, may have a significant influence on the effectiveness of HEI management.

The proposed tool for developing a ranking of strategic objectives in the light of multi-criteria evaluations can be a valuable source of information for the university management. It indicates on which strategic objectives the management should concentrate its efforts in the first place taking into account its preferences. It allows us to indicate groups of strategic objectives with different levels of importance from the point of view of the evaluators. It also provides information on which strategic objectives should be undertaken first in order to improve the situation at the university. The authors of the article are also aware of the weaknesses of the proposed tool. Developing the ranking requires the identification of strategic objectives and criteria for their assessment, which may be time-consuming. It also does not provide information on whether the higher education institution has the financial resources to implement the strategy.

2.6. Rank technique 1–10

The 0–10 ranking technique is also known in the literature. This tool has found wide application in many scientific fields [20]. There are numerous research works relating to the presented issue in the context of practical as well as theoretical research. Among the many advantages of the presented technique is a greater differentiation of the final ranks of the analysed elements. It is also emphasised that an important condition for the correct application of the 1–10 technique is the unambiguous and precise determination of the nature of the extracted and ranked elements [20]. The 0–10 technique consists of analytical comparisons of partial elements of the studied community. The tool that is used for this purpose is Table 2.

Table 2. Proposal of strategic objectives rank using 0–10 technique

Strategic objective												Ranks
C_1	4	2	5	3								14
C_2	6				4	4	3					17
C_3		8			6			9	4			27
C_4			5			6		1		7		19
C_n				7			7		6	3		23

On the left-hand side of Table 2 are the strategic objectives under analysis. The 0–10 technique consists of comparing the strategic objectives in pairs in columns and assigning individual points to them according to preference. Preferences are recorded in individual columns by distributing 10 points between two objectives that are comparable to each other. Each column serves to compare one pair of elements [20]. The greater the sum in the row of a given strategic objective, the greater its importance from the perspective of the decision-maker.

2.7. Use of 1–10 technique in higher education

The use of the 0–10 technique in higher education can be very helpful. This technique can be used to determine the rank (weights) of given strategic objectives. It can indicate which strategic objectives should be first pursued, taking into account the preferences of the decision maker. The use of the 0–10 technique has many advantages. It is a fairly simple technique and its versatility means that it can be used in the process of ranking different elements in a university. It also allows for great flexibility in determining the degree of detail in the preferences and allows balancing the importance of the compared elements in the 0–10 range. However, with a large number of comparable strategic goals, it can be time-consuming and can cause difficulties in the presentation of the findings and reduce operability [5, 20].

2.8. Other tools, methods, and approaches supporting strategic management at universities

As has been emphasised many times, universities are increasingly departing from traditional management towards strategic management. This change is most justified, the confirmation of which can be seen in many research works. Taking into account the fact that the process of strategic management of a university is extremely complex and difficult, it is necessary to search for methods and tools to support managers at all stages, i.e. planning, formulation, implementation, as well as control and monitoring. Numerous examples of these tools, methods and approaches are provided in the literature on the subject. This section presents the most important studies selected from the authors' point of view. For example, Richards et. al in one of their works present the use of scenario planning as a technique supporting the process of strategic management at universities. The presented research results show clearly that the presented tool is useful and enables institutions to assess the external environment in terms of their basic mission and strengths. The presented research also illustrates the effectiveness of scenario planning in engaging the entire university's staff, as well as stimulating their ideas and imaginations to create future strategies or plan university priorities [5]. Other, equally interesting studies were presented by Cropper and Cowton. The authors in their work proposed the use of financial scenario modelling as a tool

to support universities in the strategic management process, taking into account the uncertain financial environment [5].

The literature on the subject is rich in research, both empirical and theoretical, on various methods, tools and approaches to assist management in making decisions. Multi-criteria methods seem to be particularly useful in this area, helping decision-makers to choose the right option from a set of alternatives based on multiple criteria. It should be noted that a large part of the presented studies concern enterprises. For example, Akhavi and Hayes compare two multi-criteria decision-making techniques in one of their works: Multi-criteria rank ordering (MRO) and analytical hierarchy process (AHP). This study is intended to assist designers in choosing the right solution for them [18]. The multi-criteria methods are used in many areas of an organisation's activity. For example, the analytic hierarchy process (AHP) and PROMETHEE (preference ranking organisation method for enrichment of evaluations) method were used to make decisions in the area of logistics and location of villages' ratings. The use of multi-criteria methods in making logistic decisions has also been presented in other research papers.

3. Metodology

Figure 1 shows the implementation process of the proposed model.

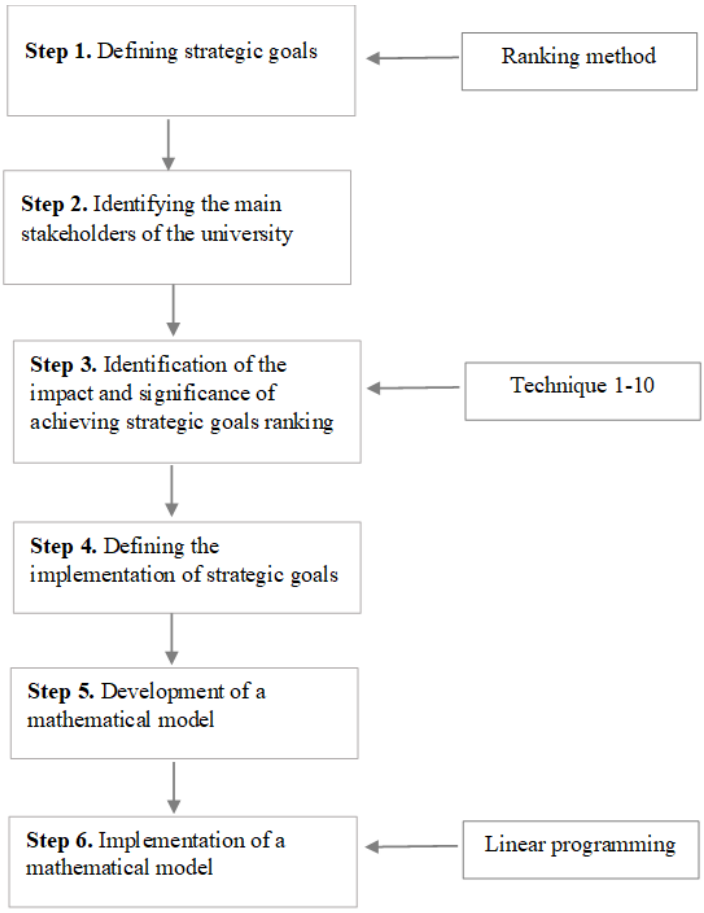

Figure 1. The model implementation process

The proposed strategy implementation model consists of six stages. The first stage is to define strategic goals. The second stage is to identify the main stakeholders of the university. In the third stage,

it is necessary to identify the impact and significance of the implementation of strategic goals on the satisfaction of university stakeholders, which will allow one to define the strategic goals of the organisation (stage 4). At a later stage, a mathematical model should be developed (stage 5) and implemented (stage 6). The steps are explained in detail below.

Step 1. Defining strategic objectives. This stage should be preceded by conducting an analysis of the strengths and weaknesses of the HEI and conducting an analysis of the organisational environment. The implementation of all strategic objectives may be difficult. The management may be faced with the problem of deciding which objectives to pursue first, which have priority given the various selection criteria. When selecting strategic goals for implementation, the following may be important: a) the implementation cost of the strategic goal, b) its importance from the perspective of various stakeholders (e.g. the goal – improvement of didactic infrastructure, which may be important from the perspective of students or the university staff, may be of lesser importance from the perspective of the university management, taking into account the maintenance of an appropriate financial policy of the university). The following may also be of significance: c) the time of the implementation of a given objective, assuming a specific period of implementation of the entire strategy, or d) access to resources necessary to realise a given strategic objective. The university management may therefore be faced with the complex problem of deciding which strategic objectives should be taken into account in the development and further management of the strategic scorecard taking into account various selection criteria. The use of the method of ranking objects in the light of multi-criteria evaluations may be helpful in the discussed scope. The proposed ranking makes it possible to indicate which objects (strategic objectives) are the most important from the evaluators' point of view and which should be selected for developing the strategic scorecard, which should be undertaken first to improve the functioning of the university. In this stage of implementation of the proposed model (step 1), the authors propose to use the ranking method according to the procedure presented by Kukuła [11]. The consequence of using this procedure is the ranking of strategic goals in the form of three groups of goals. For further analysis, the authors of the article propose to take into account only the objectives in the group of the best objects.

Step 2. Identify the main stakeholders of the HEI. These stakeholders may be directly related to the perspectives of the BSC (e.g., the perspective of university management, students, and staff) but may also include external stakeholders (employers, alumni, and ministry). This issue is discussed in detail by Ryńca [17].

Step 3. Identifying the impact and importance of achieving strategic objectives on stakeholders' satisfaction. The authors recommend that the proposed model takes into account the impact of the implementation of individual strategic objectives on student satisfaction and the assessment of their importance from the perspective of the university management. In order to determine the impact of the implementation of a strategic objective on student satisfaction, it is necessary to develop a survey questionnaire and conduct a survey. However, in the case of determining the importance of a given strategic objective from the perspective of the university management, we suggest using the 0–10 ranking technique.

Step 4. Determining the time of implementation of the strategic objectives. Implementing the strategy is a complex process. It requires a lot of both financial resources and time for its implemen-

tation. The strategic objectives are usually of a long-term nature and in their realisation factors from the environment of the HEI (political and legal factors, demographic or social factors) should also be taken into account. From the perspective of the university management, the selection of objectives may also be important in terms of the time necessary for their implementation. This is because the university management may expect a fast implementation of the strategy enabling adaptation to sudden changes in the environment (e.g. resulting from the Covid-19 pandemic). The proposed model may be helpful in this respect. Determining the time of implementation of individual strategic objectives may be conducted in a team format (top management of the HEI, deans of individual departments, and strategy specialists employed at the HEI) with the permissibility of open discussion and exchange of arguments.

Step 5. Development of a mathematical model. This stage consists of the development of a mathematical model in the form of objective and constraint functions.

Step 6. Implementation of the mathematical model in the IT environment. Currently, there are many programs on the market that allow solving linear programming problems. Examples include Solver, LindoApiSystem, Gusek, or Storm. The latter seems simple and intuitive to use. However, it is based on the currently unused DOS environment and its computational capabilities (number of variables in the model) are limited.

4. Using linear programming in strategic scorecard management. A proposed model

The implementation of strategy in a higher education institution requires the use of appropriate tools. It may be justified to use linear programming in strategic scorecard management. As mentioned earlier, the choice of strategic objectives should largely depend on their impact on the satisfaction of various stakeholders and on the time required to implement them. Different strategic objectives may have different meanings from the perspective of university management, students, or employees.

Bearing in mind that the management of the HEI should strive for a situation in which it is possible to satisfy the needs of different stakeholders as much as possible, the criterion for the selection of strategic objectives takes the form:

$$\sum_{i=1}^{n}(di_{ij}t_i)W_i \rightarrow \max \tag{9}$$

where d_i is the decision variable of introduction or rejection of the strategic objective C_i, $d_i \in [0, 1]$, t_i – the strength of the impact from the introduction of strategic objective C_i on the satisfaction of jth stakeholder, W_i – the importance of the ith strategic objective from the perspective of the university management.

Taking into account the preferences of the university management resulting from the timetable for the implementation of the strategic objectives within the adopted time perspective T and the time necessary for the implementation of the set strategic objectives in the individual perspectives of the BSC, the constraint of the presented model takes the form

$$\sum_{i=1}^{n} d_i Z_i \leq Tf \tag{10}$$

where Z_i is time of realisation of the ith strategic objective, T – time foreseen for the implementation of the university's strategy, d_i –a decision variable in the form of introduction or rejection of the ith strategic objective C_i, where $d_i \in [0,\ 1]$.

Strategic objectives may not have the same meaning (importance) W_i from the perspective of university management and have a different impact on the satisfaction of different stakeholders (students, employees, etc.). Therefore, it is necessary to select strategic objectives C_i in an optimal way, taking into account the time scheduled for the implementation of the strategy, while still focussing on the greatest possible satisfaction of the various evaluation stakeholders. We believe that it may be helpful in the case at hand to use linear programming to find the optimal solution given the constraints. As mentioned earlier, linear programming is used in the situation of a decision problem where the intention of the decision maker is to find the maximum or minimum optimal solution. The authors of the article point out a number of advantages of using the proposed method. It can be helpful in the process of strategic planning, especially in the selection of strategic objectives in the framework of individual BSC perspectives. Linear programming can provide information on the optimal choice of objectives, and initiatives in the implementation of the strategy. It also allows evaluating a higher education institution from the point of view of different perspectives, in a comprehensive manner with the occurring limitations. The authors of the article are also aware of the limitations resulting from the application of the proposed model, in particular, the high time consumption connected with the development of the model. The limitations may result mainly from the lack of managerial knowledge regarding the development of the mathematical model, which may make it difficult or impossible to apply. The proposed solution also requires the use of IT tools for calculations (e.g., AMPL, SOLVER, GUSEK, STORM or others).

5. The use of ranking and optimisation methods in strategic management in higher education - a case study

The research was conducted in the form of the authors' proposal for a public higher education institution in the city of Wrocław, Poland. In step 1 of our proposed model, identification of strategic objectives, 16 strategic objectives were specified in four areas of HEI activity: educational activity, scientific research, cooperation with the environment and material base and organisational efficiency. This stage was preceded by a detailed analysis of the strengths and weaknesses of the university, as well as an analysis of the organisational environment. The following was listed:

C_1 – strengthening of international cooperation,
C_2 – modification of the educational offer favouring the internationalisation of HEI
C_3 – strengthening regional and national cooperation,
C_4 – involvement of the university in the process of improving the competencies of primary and secondary school teachers,
C_5 – adjusting the educational offer of HEI to the offers of the labour market.

C_6 – improving the level of matching the competencies of graduates with the needs of the labour market,

C_7 – broadening the scope and increasing the number of initiatives aimed at young people.

C_8 – improvement of the quality of education,

C_9 – intensification of scientific and research undertakings with the participation of national and foreign entities,

C_{10} – broadening the scope, increasing the quality and efficiency of research,

C_{11} – promotion of attitudes and activities in the field of innovation and creativity of academic teachers,

C_{12} – to improve the use of the infrastructural resources and intellectual potential of the university,

C_{13} – to cooperate with employers in supporting the didactic process (conducting specialized classes for practitioners),

C_{14} – promoting in human resources policy people strongly connected with the academic environment, involved in the life of the university,

C_{15} – supplementing the staff with national and international scientific authorities,

C_{16} – creating a system of support for the development of the employed research and teaching staff: making it possible to obtain successive degrees of scientific promotion, realisation of employee exchange programmes, making it possible to participate in training courses and conferences; Out of the sixteen strategic objectives of the HEI defined in turn $C_1, C_2, \ldots, C_{16}$.

In the final stage six priority objectives (of the highest importance in the process of HEI strategy implementation) will be presented. The order of the presented strategic objectives in the ranking is determined by diagnostic variables, listed on the basis of a structured interview conducted with the management of the HEI. Thus, the following can be listed:

X_1 – cost of implementation of the strategic objective,

X_2 – importance of the strategic objective,

X_3 – implementation time of the strategic objective.

X_4 – access to resources necessary to achieve a given strategic objective.

For individual diagnostic variables, a scale from 1 to 5 was adopted, where, for variables X_1, X_2, 1 means very low, 2 – low, 3 – medium, 4 – high, 5 – very high. For variable X_3, 1 means very short, 2 – short, 3 – medium, 4 – long, and 5 – very long. For the variable X_4, 1 indicates very easy, 2 – easy, 3 – medium, 4 – difficult, and 5 – very difficult. Table 3 presents numerical information on the values of the diagnostic characteristics, obtained from a structured interview with university management. Of the four variables presented: X_1 and X_3 are destimulants, while the variables X_2 and X_4 stimulants, hence $X_1, X_3 \in D$ and $X_2, X_4 \in S$.

The recognition of variables affects the way they are normalized. Completing the process of normalising the diagnostic characteristics allows us to move to the aggregation stage. As a result, we obtain aggregate variables that characterise each of the 16 strategic objectives of the university.

Table 3. Numeric values diagnostic features

Strategicobjective	Diagnostic variables			
	X_1	X_2	X_3	X_4
C_1	3	5	5	4
C_2	3	4	2	2
C_3	2	5	3	3
C_4	1	2	3	1
C_5	3	4	2	2
C_6	3	4	2	2
C_7	2	4	3	3
C_8	2	5	3	1
C_9	4	5	5	4
C_{10}	4	5	5	4
C_{11}	2	3	2	1
C_{12}	1	3	2	1
C_{13}	2	4	2	2
C_{14}	2	3	2	1
C_{15}	3	5	3	3
C_{16}	2	3	2	1

Table 4. The normalized values of the diagnostic variables and the values of the synthetic variable

Strategic objective	Z_{i1}	Z_{i2}	Z_{i3}	Z_{i4}	**Q**
C_1	0.5	1	0	0.75	2.25
C_2	0.5	0.67	0.75	0.25	2.17
C_3	0.75	1	0.5	0.5	2.75
C_4	1	0	0.5	0	1.5
C_5	0.5	0.67	0.75	0.25	2.17
C_6	0.5	0.67	0.75	0.25	2.17
C_7	0.75	0.67	0.5	0.5	2.42
C_8	0.76	1	0.5	0	2.25
C_9	0.25	1	0	0.75	2
C_{10}	0.25	1	0	0.75	2
C_{11}	0.75	0.33	0.75	0	1.83
C_{12}	1	0.33	0.75	0	2.08
C_{13}	0.75	0.67	0.75	0.25	2.42
C_{14}	0.75	0.33	0.75	0	1.83
C_{15}	0.5	1	0.5	0.5	2.5
C_{16}	0.75	0.33	0.75	0	1.83

The results of the normalisation of diagnostic features and values of aggregate (synthetic) variables Q are presented in Table 4. Based on the multi-criteria evaluation, a ranking of strategic objectives of the HEI was prepared. Six priority ones (with the highest relevance in the university strategy implementation process) will be further analysed:

C_3 – strengthening regional and national cooperation,

C_{15} – supplementing the staff with national and international scientific authorities,

C_7 – broadening the scope and increasing the number of initiatives aimed at young people,

C_{13} – to cooperate with employers in supporting the didactic process (conducting specialized classes for practitioners),
C_1 – strengthening of international cooperation,
C_8 – improvement of the quality of education.

For the purpose of this study, two stakeholder groups were selected at step 2: management and students. Step 3 was also used to identify the impact of strategic objective implementation on student satisfaction and to assess their importance (significance) from the perspective of the university management. A survey questionnaire was used to assess the impact of strategic objective implementation on student satisfaction. The survey was administered to a group of 30 students. The students' task was to assign to each strategic objective an appropriate weight in the steel from 1 to 5, where 1 – means very low, 2 – low, 3 – medium, 4 – high, and 5 – very high. Table 5 presents the assessment of the impact of the implementation of the strategic objective on student satisfaction.

Table 5. Assessment of the impact of the strategic objective on student satisfaction

Strategic objective		Impact
C_7	expanding the scope and increasing the number of initiatives aimed at young people	4.8
C_{13}	cooperation with employers in supporting the didactic process (conducting specialized classes for practitioners)	4.8
C_1	strengthening international cooperation	4.2
C_8	increasing the quality of education	4.2
C_{15}	supplementing the staff with national and international scientific authorities	4.0
C_3	strengthening regional and national cooperation	3.6

Table 6. Weight of strategic objective on management satisfaction

Strategic objective	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Ranks
C_3	7	8	6	4	4											29
C_{15}	3					6	3	2	4							18
C_7		2				4				3	1	2				12
C_{13}			4				7			7			4	4		26
C_1				6				8			9		6		5	34
C_8					6				6			8		6	5	31

Table 7. Implementation time selected strategic objective of the HEI

Strategic objective	Implementation time in months
C_3	15
C_{15}	10
C_7	12
C_{13}	13
C_1	20
C_8	12
Total	82

The strategic objectives C_7 and C_{13} have the highest impact on the satisfaction of the surveyed group (students). In the case of determining the importance of the weight of a given strategic objective from the perspective of the university's management, the 0–10 ranking techniques were used. Table 6 presents a summary of the weights of the strategic objectives of the university from the perspective of the university's management. In the management's assessment, the highest weights were given to the following objectives: C1, C8, and C3. In step 4, based on the interview with the management of the university, the time of implementation of the six strategic objectives of the university was determined. The obtained results are presented in Table 7.

In step 5, a mathematical model was developed whose objective function takes the form:

$$(4.8 \times 12)d_7 + (4.8 \times 26)d_{13} + (4.2 \times 34)d_1 + (4.2 \times 31)d_8 + (4.0 \times 18)d_{15} + (3.6 \times 29)d_3 \rightarrow \max$$

The university management adopted a 48-month strategy implementation period. Accordingly, the following constraints based on the timing of the strategic objectives were formulated:

$$12d_7 + 13d_{13} + 20d_1 + 12d_8 + 10d_{15} + 15d_3 \leq 48$$

At stage 6, the mathematical model presented above was implemented in a selected IT environment. For the purpose of this study, AMPL program was used.

AMPL

```
ampl: model 'C:\AMPL\Examples\new_model_higher.mod';
maximize value:
        57.6*d[1] + 124.8*d[2] + 142.8*d[3] + 130.2*d[4] + 104*d[5] +
        104.4*d[6];

subject to school:
        12*d[1] + 13*d[2] + 20*d[3] + 12*d[4] + 10*d[5] + 15*d[6] <= 48;

CPLEX 20.1.0.0: optimal integer solution; objective 416.6
3 MIP simplex iterations
0 branch-and-bound nodes
d [*] :=
1  1
2  1
3  0
4  1
5  1
6  0
;

value = 416.6

ampl:
```

Figure 2. Implementation of the mathematical model for a period equal to 48 months.

Figure 2 presents the implementation of the mathematical model along with the results obtained. A period of 48 months was assumed for the implementation of the strategy. In the presented period, the university can implement four out of six strategic objectives (C_7 – an extension of the scope and increasing the number of initiatives aimed at young people, C_{13} – cooperation with employers in terms of supporting the teaching process (conducting specialized classes for practitioners, C_8 - Improving the quality of education, C_{15} Complementing the staff with national and international scientific authorities), thus achieving the satisfaction of stakeholders at the level of 63%. By extending the strategy implementation process by 12 months (up to 60 months) the university can achieve four more strategic objectives (C_{13} Coop-

eration with employers in supporting the teaching process (teaching specialist classes for practitioners, C_1 Strengthening international cooperation, C_8 Improving the quality of education, C_3 Strengthening regional and national cooperation) and achieve $(502.2/633.8) \times 100\% = 79\%$ of stakeholders' satisfaction with the strategy implementation (Figure 3). To achieve all the assumed strategic goals, a period of 82 months is necessary[1].

```
AMPL
ampl: model 'C:\AMPL\Examples\new_model_higher.mod';
maximize value:
        57.6*d[1] + 124.8*d[2] + 142.8*d[3] + 130.2*d[4] + 104*d[5] +
        104.4*d[6];

subject to school:
        12*d[1] + 13*d[2] + 20*d[3] + 12*d[4] + 10*d[5] + 15*d[6] <= 60;

CPLEX 20.1.0.0: optimal integer solution; objective 502.2
1 MIP simplex iterations
0 branch-and-bound nodes
d [*] :=
1  0
2  1
3  1
4  1
5  0
6  1
;

value = 502.2

ampl:
```

Figure 3. Implementation of the mathematical model for a period equal to 60 months.

6. Conclusions

Dynamic changes in the university environment have resulted in the fact that, like many business organisations, also universities have become one of the entities operating on the competitive services market. The unpredictability of the environment, competition for students, qualified employees and funds force modern universities to search for new methods and tools supporting the strategic management process. In the light of the conducted research, it seems particularly important to search for tools supporting the management staff in the decision-making process. The university management may therefore be faced with a complex decision-making problem as to which strategic goals should be considered in the development and subsequent management of the strategic scorecard, taking into account various selection criteria.

The authors of the article conducted detailed literature research on strategic management at universities and the tools supporting this process. As a result of the work carried out, it was shown that the process of strategic management at universities still requires improvement, and there is no effective tool supporting strategic management using, for example, object-oriented ranking in the decision-making process at universities.

The approach presented in the article, aimed at supporting the decision-making process by university managers, has many advantages. Firstly, it allows indicating which strategic goals are the most important

[1]The sum of total stakeholder satisfaction with the level of the implemented strategy 663.8.

from the evaluators' point of view, which should be undertaken in the first place in order to improve the functioning of the university. Secondly, the authors' approach presented in the article integrates the methods and tools of multi-criteria decision-making. This is because it enables the optimal selection of goals with the existing time constraints of the strategy implementation. Thirdly, it makes it possible to identify the impact and importance of the implementation of strategic goals on the satisfaction of stakeholders, which may be an important stage in the so-called sustainable approach to the evaluation and management of the strategy implementation process. Fourthly, it is a relatively simple set of methods and tools that could also be used by managers who do not have adequate experience or substantive preparation for university management, resulting mainly from the specificity of Polish higher education. The authors of the article are also aware of some weaknesses in the use of linear programming. This method can be time-consuming to implement. It requires the knowledge of the time to achieve strategic goals and access to software in order to perform calculations. It also requires skills related to developing a mathematical model.

In light of the research conducted, it is also worth emphasizing that the model presented by the authors is characterised by a certain simplicity. With full awareness, we focused only on selected aspects (variables in the mathematical model) that have a significant impact on the decision-making process at universities. The fact that in this study it was not decided to introduce additional restrictions in the presented model, it is not synonymous with the lack of such a possibility. For example, the next direction of research will be the expansion of the proposed model with other ranking tools and methods, and the expansion of the mathematical model with a number of new limitations, such as access to funds necessary to implement the strategy. However, this requires extensive research in the field of costing the implementation of strategic goals, including the use of new calculation methods, such as, for example, activity-based costing. According to the authors, the presented form of the model increases its utilitarianism and potential implementation possibilities.

It is planned at a later stage to expand the proposed model with other ranking tools and methods. However, this requires extensive research in the area of costing the implementation of strategic goals, including the use of new calculation methods, such as, for example, activity-based costing.

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