Janusz Wielki[*], *Magdalena Jurczyk-Bunkowska*[**]

Evaluation of Healthcare Business Intelligence Using the Fuzzy TOPSIS Method

This article addresses the assessment of BI systems to put forward recommendations for implementing this type of solution at the University Clinical Hospital in Opole (UCHiO). The aim of the article is to propose methodologies for evaluating such schemes in terms of benefits and costs. The first stage of the study based on literature analysis identified the potential benefits of implementing BI for hospital environment. Based on this, a preliminary list of criteria was formulated, which was verified and adapted to the strategy of UCHiO using the technique of direct interview. This led to the definition of a set of criteria allowing the evaluation of BI systems in UCHiO. It includes fourteen assessment areas for benefits, five for costs and one for risk. For criteria relating to benefits and risks, the assessment of solutions requires the opinion of experts. They are imprecise and therefore are presented in the form of linguistic values. On the other hand, the values of the criteria referring to costs could be estimated precisely enough to be presented in the form of numerical values. An evaluation of BI systems was proposed and allowed for making the recommendations in the form of a specific map. Its essence is to show the place of any alternative solution in relation to the benefits it is supposed to bring to the hospital and the costs that the hospital will have to incur in connection with its implementation. This required the transformation of expert assessments into a synthetic indicator of benefits of implementing the BI systems in UCHiO. The fuzzy TOPSIS technique was used for this purpose. The article details the calculations leading to obtaining the indicator. The prepared evaluation map of the BI systems enabled the formulation of conclusion referring to recommendations of specific decisions regarding actions leading to the implementation of the BI in the hospital. The original evaluation methodology proposed in the article can be used in different healthcare units after the criteria weights are verified according to the adopted strategy.

Keywords: Business Intelligence (BI), evaluation, multicriteria decision, fuzzy TOPSIS technique.

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Wykorzystanie rozmytej metody TOPSIS do oceny i porównania systemów klasy Business Intelligence

Artykuł dotyczy problemu oceny systemów BI na potrzeby rekomendacji wdrożenia tego typu rozwiązania w Uniwersyteckim Szpitalu Klinicznym (USK) w Opolu. Celem artykułu jest zaproponowanie metodyki ewaluacji takich systemów pod kątem korzyści i kosztów wynikających z ich wdrożenia. Na pierwszym etapie badań na podstawie analizy literatury wskazano potencjalne korzyści z wdrożenia systemów BI dla szpitala. Na jej podstawie sformułowano wstępną listę kryteriów, którą zweryfikowano i dopasowano do strategii USK w Opolu, wykorzystując technikę wywiadu. Doprowadziło to do zdefiniowania zbioru kryteriów pozwalającego dokonać ewaluacji systemów BI w USK w Opolu. Obejmuje on czternaście obszarów oceny odnoszących się do korzyści, pięć – do kosztów oraz jeden – do ryzyka. W przypadku kryteriów odnoszących się do korzyści i ryzyka przyporządkowanie oceny rozwiązań wymaga opinii ekspertów. Są one nieprecyzyjne i dlatego zostały przedstawione w postaci wartości lingwistycznych. Natomiast wartości kryteriów odnoszących się do kosztów mogły zostać oszacowane na tyle precyzyjnie, by zdecydowano się na ich przedstawienie w postaci wartości liczbowych. Zaproponowano przedstawienie ewaluacji systemów BI pozwalającej na dokonanie rekomendacji w formie swoistej mapy. Jej istotą jest pokazanie miejsca każdego alternatywnego rozwiązania w odniesieniu do korzyści, jakie ma przynieść dla szpitala i kosztów, które szpital będzie musiał ponieść w związku z jego wdrożeniem. Wymagało to przekształcenia ocen eksperckich w syntetyczny wskaźnik korzyści wdrożenia systemów BI w UCHiO. Wykorzystano w tym celu rozmytą metodę TOPSIS. Artykuł prezentuje szczegółowo obliczenia prowadzące do jego uzyskania. Przygotowana mapa ewaluacji systemów BI pozwoliła na sformułowanie wniosków odnoszących się do rekomendacji określonych decyzji odnośnie do działań prowadzących do wdrożenia systemu BI w szpitalu. Zaproponowana w artykule oryginalna metodyka ewaluacji może być zastosowana w różnych jednostkach służby zdrowia po weryfikacji wag kryteriów tak, by odpowiadały strategicznym celom jednostki.

Słowa kluczowe: systemy Business Intelligence (BI), ewaluacja, wielokryterialne podejmowanie decyzji, rozmyta metoda TOPSIS.

JEL: M15

1. Introduction

The University Clinical Hospital in Opole (UCHiO) is undergoing enormous changes. They are related, among other things, to the opening of a medical faculty at the University of Opole. Introducing new solutions is aimed at improving the efficiency of the implemented medical and didactic processes. This requires an even stronger bond between medium and long-term decisions and data that is collected by numerous hospital IT systems. Currently, the controlling reports are performed using the ready sheets of standard office software. However, the increasing complexity of the operations reduces the rationality of such an approach. The number of defined key performance indicators and the number of information sources are increasing. Thus, more and more time is devoted to the preparation of reports. On the other hand, the high dynamics of hospital development means that decisions regarding planning and budgeting should be made faster and faster. In addition, coordinating medical processes with national healthcare programs and monitoring the level of medical errors are becoming more and more time-consuming. In the aspect of conducted scientific and didactic processes, what is valuable is the evaluation of the effectiveness of applied therapies, determination of the correlation between the length of stay in hospital and the patient's characteristics, and transparency and completeness of medical procedures.

The above-mentioned needs lead to increased requirements regarding the availability of information and data analysis. The solution is provided by professional business intelligence (BI) systems, which are often used in healthcare organizations supporting administrative and clinical processes (Foshay & Kuziemsky, 2014). However, the decision to implement a professional BI system must be preceded by an adequate analysis. Changing the existing way of collecting and processing information needed to make medium- and long-term decisions requires a multi-criteria assessment. It should cover issues related to financial resources, human resources and technical aspects. Its essence is to determine to what extent alternative BI systems are better than the currently used solutions. Thus, this type of analysis must take into account not only the potential of the BI class system itself, but also the possibilities of its use in a specific organization (Dyczkowski, Korczak, & Dudycz, 2014). There are many BI class software providers on the market that have their strengths and weaknesses. Often, the use of the system functionality is determined by technical and personnel changes in the organization. The managers must, from the perspective of their own organization, consider the grounds for implementing BI class software and make their own selection, which is connected with the answer to the question: How to assess the value of a BI system for decision-making processes in a given hospital in terms of justifying the costs incurred for its purchase, implementation and operation?

Such considerations are based on a multi-criteria expert assessment, involving imprecise knowledge. They are supported by fuzzy techniques such as TOPSIS, ELECTRE, AHP and VIKOR. As the research shows, the fuzzy TOPSIS method is applied most frequently, amounting to around 30% of all applications (Aruldoss, 2013). For this reason, it has been used in the methodology for the evaluation of BI systems proposed in this article in terms of meeting the requirements of such a recipient as a hospital. The following chapter of the article presents an overview of the literature indicating the benefits of implementing BI systems in hospitals, also referring to the conditions of the development of healthcare services in Poland. Chapter 3 focuses on the assessment of BI systems. It shows the methods and criteria relating to the assessment of BI systems in enterprises and hospitals. Chapter 4 discusses research methodology, while the next one presents its effects in the form of agreed criteria for assessing BI systems at the UCHiO. Chapter 6 contains a detailed example of calculations for the comparison of alternative data processing and analysis solutions and presents the concept of their comparison. The article is summarized by conclusions referring to the limitations and benefits of the proposed methodology.

2. The Role of BI Systems in Hospital Management

Hospitals in Poland, and not only, are facing such challenges as population growth, poor patient role in treatment decisions, lack of cooperation in current hospital communication system, long waiting time before receiving treatment and many dissatisfied patients (Porter, 2006). The radical improvement of information flow is the key to overcome the above-mentioned problems. Information technology is perceived as a source of transformation that ensures better quality of healthcare in order to enable better access to care and to lower the overall costs (Black, et al. 2011). BI systems can help by handling and analyzing a vast amount of data (Geetha, 2017). Wu et al. (2007) defined BI as a business management term describing applications and technologies that are used to gather, provide access to, and analyze data and information about the organization to help the management make better business decisions. These systems are important especially for the healthcare sector, which generates large amounts of data. However, the challenges in handling such big data are not just about the volume. The challenges include capturing, storing, searching for, sharing, analyzing, and then finding insights from complex, noisy, heterogeneous, longitudinal, and voluminous data (Madsen, 2014).

2.1. Benefits of Implementing BI Systems in Hospitals

The basic role of BI systems is gathering, analyzing and distributing information. Thanks to this, they support decision-making processes (Ghazanfari, Jafari & Rouhani, 2011). Before the era of computer technology, decisions were made mainly on the basis of estimates, assumptions and intuition. Currently, we prefer to rely on hard data collected from information systems (Tunowski, 2015). However, the process of collecting and processing data is very labor-intensive. By implementing BI, organizations are able to significantly reduce the time required for data collection, data processing and analysis (Bara, 2013).0 Based on a review of the literature, Tunowski (2015) lists further benefits of implementing BI systems in organizations:

- the ability to start the changes which, as a result, lead to the creation of an intelligent organization based on knowledge and learning;
- the possibility of effective measurement of data sets;
- significant reduction of time dedicated to the collection and processing of data;
- using advanced data visualization. Its advantage lies in much greater information capacity compared to a traditional visualization.

Considering the benefits of implementing BI systems from the hospital's point of view, the published studies list the following:

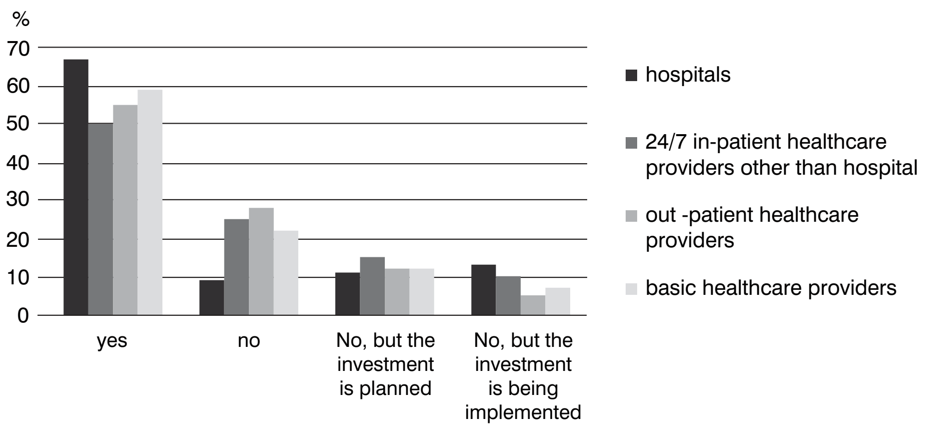
- improvements in hospital process performance (Ali, Nassif & Capretz, 2013) Ferranti et al., 2010);
- enabling clinicians to explore patterns in data and identify patients at risk (Ciurea et al., 2016);
- improvement in treatment procedures (Ali-Özkan, Crvenkovski & Johnson, 2016);
- developing clinical indicators for services quality measurement, patient quality of life analysis (Loreto et al., 2017);
- better data management and creating a unique repository (Sabherwal & Becerra-Fernandez, 2011).

2.2. Information Needs in the Polish Healthcare System

Striving to improve the performance of healthcare is based on the optimal use of healthcare databases, the existing material, and financial and personnel resources (medical personnel, along with their skills), devoted to their activities (Kolowitz & Shresth, 2011). Among the shortcomings in units of the Polish healthcare system are the following: implementation of information systems not related to the relevant organizational changes and lack of co-operation of information systems (Olszak & Batko, 2012). The existing solutions do not ensure interoperability, and the lack of cooperation between systems makes management of information impossible and adversely affects the accuracy, integrity, comparability and completeness of data.

There are a number of forthcoming large-scale healthcare digitalization projects in the near future. The government has inscribed basic e-health developments into the law. According to the 2017 bill, there are new deadlines for keeping medical records in the electronic form. Medical records specified by the Minister of Health should be held in the electronic form from 2019, and their electronic exchange must be available by 2021. Electronic prescriptions should be obligatory from 2020. E-referrals should enter into force from 2021 (Bukowski & Pogorzelczyk, 2019). The implementation of "e-health" solutions has taken on the dynamics in recent years. Research shows that it is most advanced in hospitals (Figure 1), which should become leaders also in the area of data processing and analysis.

Figure 1. Availability of infrastructure necessary to carry out individual records electronic documentation in 2018



Source: Bukowski & Pogorzelczyk (2019).

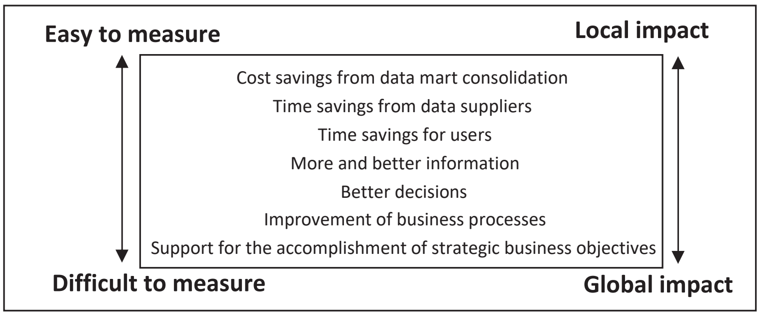
3. Evaluation of BI Systems

One of the most frequently mentioned benefits of business intelligence is the support in better decision-making (Carver & Ritacco, 2006), (Atre & Moss, 2003). However, the assessment of the effects it can bring to the organization is carried out on the basis of different types of criteria (Nyblom, et al. 2012). In the evaluations made by business intelligence and analytics platforms such as Magic Quadrant, Gartner's Business Analytics Framework or Dresner Advisory Services, technical aspects dominate. The focus is not on the process itself, but on the technologies, algorithms and tools that enable saving, recovery, manipulation and analysis of data and information (Bucher, Gericke & Sigg, 2009). BI systems are evaluated in these sets according to criteria such as: ability to write to transactional applications; ad-hoc query; advanced visualization; big data support; collaborative support for group-based analysis; complex event processing; data mining and advanced algorithms; data visualization; end user "self-service"; in-memory support; interactive analysis; personalized dashboards; vertical/functional analytical applications; social media analysis. Multi-criteria evaluation of BI systems, from a technical point of view, can also be found in scientific works (Dyczkowski, Korczak, & Dudycz, 2014).

The assessment of BI systems, however, is also carried out from managerial viewpoints, which see BI as a process in which data gathered from inside and outside the enterprise are integrated in order to generate information relevant to the decision-making process (Ghazanfari, et al., 2011). Here, the role of BI is to create an informational environment in which operational data gathered from Transactional Processing Systems (TPS) and external sources can be analyzed in order to extract "strategic" business knowledge to support the unstructured decisions of management. From this perspective, the emphasis is on the excellence of management decision-making process (Bose, 2009). The criteria of the benefit for this type of assessment are related to (1) an increase in revenue; (2) an increase in profit; (3) improving customer satisfaction; (4) a reduction of costs; and (5) an increase in market share (Atre & Moss, 2003). However, their direct measurement is impossible due to their being global in scope (Figure 2) and immaterial (Watson & Wixom, 2007). For this reason, classical methods such as Return of Investment (ROI) do not work in the case of evaluation of BI systems (Carver & Ritacco, 2006). Hence the difficulty in the economic assessment of whether they are worth the funds invested in them (Hočevar & Jaklič, 2010).

The perceived value of IT solutions is strongly dependent on the subjective assessment and needs of the organization. This article focuses on BI systems for hospitals. Their basic feature is the integration with the used medical software such as electronic medical records (EMR) or medical accounting. They can be used to analyze things such as clinic or practice data (e.g. diagnostics), patient feedback, finances and patient care (e.g. treatment progress). These tools can also help interpret medical research from a variety of publications or other sources to shed light on cutting-edge technology and new lines of thought within the medical community. Therefore, for their evaluation, criteria relating to improving the health outcomes of patients are applied (Isazad Mashinchi, Ojo & Sullivan, 2019). The prices of healthcare BI software will vary depending on functionality and deployment.

Figure 2. Spectrum of BI benefits in the context of its impact and measurement possibilities



Source: Watson & Wixom (2007).

The literature discusses the issue of IT systems assessment for the healthcare sector referring to the developed maturity models (Carvalho, Rocha & Abreu, 2016). They usually refer to the HIS (Hospital Information System) as a whole. However, there are very few models of maturity developed for BI systems in healthcare. One of them is the adaptation of DeLone and McLean's IS Success Model consisting of six constructs, including Information Quality, System Quality, User Satisfaction, Use, Individual Impact and Organization Impact (Gaardboe, Nyvang & Sandalgaard, 2017). Another, much more extensive, one is the ISMETT model comprising 23 components which have been grouped in four different areas: functional, technological, diffusional and organizational (Gastaldi, at al. 2018). However, the proposed approaches do not explicitly address the issue of choosing the right BI system for a specific organization, in this case a specific hospital. Such BI system evaluation was carried out for the enterprise using the fuzzy TOPSIS method (Rouhani, Ghazanfari & Jafari, 2012). It was conducted based on the criteria of benefits from the BI systems from the technical and managerial points of view. However, this assessment did not include criteria relating to costs, which are usually described in sharp values – numbers. It is necessary from the perspective of an organization financed from public funds.

4. Research Approach

The aim of the article is to propose a method for assessing BI systems in terms of their value for the functioning of the organization such as a hospital. The problem posed concerns the question of whether the implementation of a BI system will help to achieve the effects justifying the incurrence of certain costs related to the purchase, implementation and operation of the system. Systems implemented in other hospitals in Poland are taken into account. Thanks to this, it was possible to gain knowledge about the obtained effects and incurred costs.

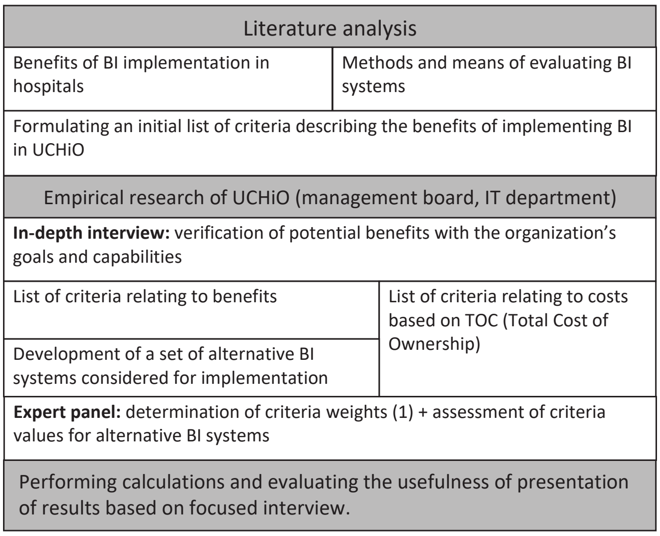
The ongoing research is intended to develop and verify the methodology for determining the ranking of data analysis and processing systems for hospital purposes. The answer to such a question requires an assessment of the needs and capabilities of a particular organization. At the preliminary stage of the research, it was assumed that most needs are typical for units in a given sector. Therefore, the focus was on the literature concerning the information needs of hospitals with an indication of the healthcare units functioning in Poland. Thanks to the applied queries and analysis of publications, the potential effects of BI implementation in the hospital were indicated. On this basis, an initial list of BI evaluation criteria was prepared, which was then verified on the basis of an in-depth, direct interview with the hospital manager.

The next stage of the research included two tasks: determining the significance of the criteria in the assessment (1) and assigning the assessment values according to each criterion for each of the alternative data processing and analysis solutions (2). Both research tasks were carried out using the form of a panel of experts. This method allowed for combining the knowledge of people related to both the hospital and the university. The proposed form of research was aimed at unification of the assessment, because it was not possible to obtain the help of one expert who had knowledge about all analyzed IT systems and was able to refer to both clinical and managerial issues.

Based on the analysis of the literature, the original methodology for processing the results of the evaluation was proposed. Data regarding assessments related to benefits were fuzzy. On the other hand, the data on costs were of a clear-cut nature. The authors decided to use the fuzzy TOPSIS method to establish a synthetic benefit indicator. In order to get a full picture, or to present the connection of benefits and costs of alternative solutions, an approach based on the idea of a risk map was proposed. The aim was to evaluate alternative BI solutions and recommend specific ones. Due to the confidentiality of the conducted research resulting from the hospital's negotiating position, in the presented example, the names of the considered BI systems and estimates of the costs of their implementation have not been disclosed.

The final stage of the research was the verification of the proposed evaluation methodology in terms of its usefulness for the decision-maker. It was based on a focused interview with the hospital manager, including presentation of a map of BI systems evaluation. The diagram of the tests carried out is shown in Figure 3.

Figure 3. Structure of research works carried out for the assessment of BI systems at UCHiO



Source: Authors' own elaboration.

5. Determination of Criteria for Comparison of Alternative BI Systems for UCHiO

While determining criteria for the assessment of BI systems, they were divided into two categories: subjective and objective. The first group mostly concerns the benefits of implementing systems of this class in the hospital.

They require an assessment in the form of preferences expressed by experts. The objective criteria refer to the costs which, given the knowledge of the BI system implementation parameters such as the number of users and a given infrastructure, can be estimated with sufficient precision.

5.1. Subjective Criteria for Evaluating BI Systems

For the preparation of the preliminary list of criteria, literature analysis was used, in particular the research work of Olszak and Batko (2012). The subjective criteria refer to the benefits that are achievable for the hospital thanks to the implementation of the BI system and (the last criterion) to the risk. The subjective criteria for the evaluation of BI systems for the hospital are shown in Table 1. It also includes the significance of each of the criteria defined on the 1–5 scale.

The criterion designated as F15 was transformed from the original "cost of risk" to "risk acceptance", so that all criteria were of the type "larger are better". In this way, the need to normalize the values of ratings in later transformations was avoided.

Evaluation of BI systems according to the criteria presented in Table 1 is imprecise and uncertain. It is not possible to assign sharp values to individual alternatives. Therefore, experts making judgments may be undecided, preferring to use interval judgments in a linguistic form. The use of imprecise values for making decisions is possible thanks to the introduction of fuzzy set theory.

Table 1. Fuzzy criteria for evaluating BI systems adopted for UCHiO

Designation of the criterion	Characteristics of the criterion	Attribute grade
F1	The ability to analyze consolidated clinical, administrative and financial data.	4
F2	Data protection through an efficient system of data access levels.	2
F3	Data management during data ingestion, data integration, data preparation.	3
F4	Fast analytics supporting clinical decisions.	5
F5	Including in the analysis the semi-structured and unstructured data.	4

Tabela 1. (cd.)

Designation of the criterion	Characteristics of the criterion	Attribute grade
F6	Predictive financial analysis.	3
F7	Support for scientific analysis: making and testing hypotheses.	3
F8	Detection of irregularities, frauds and embezzlement.	2
F9	Data exchange with external entities enabling the improvement of treatment and patient care.	4
F10	Assessment of the performance of units, e.g. people, departments.	3
F11	Monitoring the use of equipment and materials.	3
F12	Potential for the application of Big Data technology.	3
F13	Profiling and personalization of results presentation (static, dynamic reports, charts, diagrams).	4
F14	Self-service interface that make it possible to limit the participation of the IT department in the preparation of analyzes.	2
F15	Acceptability of risk (related to technology, integration with existing systems, supplier's position on the market, recommendations, and trust in-the implementing company)	1

Source: Authors' own elaboration

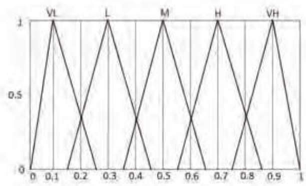
5.2. The Use of Linguistic Variables and Fuzzy Logic in the Assessment of Subjective Criteria

In a situation where it is difficult to express individual assessments in the form of specific numerical values, verbal descriptions are used, such as: "low", "medium" and "high". These values are ambiguous and imprecise, and therefore difficult to interpret. For the correct inference based on the quantities expressed in such a "fuzzy" way, it is necessary to introduce a logic different from classical. There are many different representation formats that can be used in each model, such as preference orderings, utility values, multiplicative preference relations, fuzzy preference relations and so on. Every representation format has its own advantages and disadvantages, such as precision or ease of use and understanding. The use of fuzzy sets theory has achieved very good results for modeling qualitative information. Such modeling can be treated as a mechanism that mimics the human inference process with fuzzy information. It is a tool that can compute with words the qualitative human thought process in the analysis of complex systems and decisions. Therefore, fuzzy logic is appropriate for unstructured decision-making (Afsordegan, at al., 2016).

It was decided to assign criteria to five degrees of validity according to the empirical method described in Yang and Hung (2007). As a rule of thumb, each rank is assigned an evenly spread membership function that has an interval of 0.30 or 0.25. The equivalence between the importance of an attribute and triangular fuzzy numbers (FN) is presented in Figure 4.

Figure 4. Transformation for fuzzy triangular membership functions

Rank	Attribute grade	Membership functions
Very low (VL)	1	(0.00; 0.1; 0.25)
Low (L)	2	(0.15; 0.30; 0.45)
Medium (M)	3	(0.35; 0.50; 0.65)
High (H)	4	(0.55; 0.70; 0.85)
Very high (VH)	5	(0.75; 0.90; 1.00)



Source: Yang (2007).

5.3. Objective Criteria for Evaluation of BI Systems

While assessment of the benefits of using BI systems is difficult to perform and requires expert knowledge, the cost estimate is much simpler to carry out. Suppliers offer different pricing models, but usually the cost of access depends on the number of users. Therefore, the costs of using BI solutions in hospitals depend on the needs defined by them. The total cost of ownership (TOC) was used to develop the cost-related assessment criteria for BI systems. The values obtained by the IT department were converted into volumes per year assuming a three-year period of use and a traditional form of licensing (perpetual). Table 2 presents cost-related criteria for the assessment of BI systems. They are objective, which means that they are numerical values (monetary units) which enable a comparison of alternative BI systems. In the further part of the proposed methodology, the values of S1–S5 criteria evaluations expressed in monetary units were summed up showing the annual cost of using the system.

Table 2. Objective criteria for evaluation of BI systems adopted for UCHiO

Designation of the criterion	Description of the cost-related criterion
S1	License cost (perpetual / 3 years)
S2	Cost of implementation (installation, data migration, system synchronization, staff training) / 3 years
S3	Cost of adapting the IT infrastructure / 3 years
S4	Annual cost of maintenance and service (updates, functional adjustments, etc.)
S5	Annual savings in administration resulting from shortened time for analysis and reporting

Source: Authors' own elaboration.

6. Use of the Fuzzy TOPSIS Technique for Evaluation of BI Systems

6.1. The Essence of Fuzzy TOPSIS Technique

Multiple Criteria Decision Making (MCDM) is a procedure that consists in finding the best alternative among a set of feasible alternatives. Among the many compensatory approaches of MCDM, one is the Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method. This approach is employed for four main reasons (Wang & Chang, 2007):

- TOPSIS logic is rational and understandable;
- The computation processes are straightforward;
- The concept permits the pursuit of the best alternatives for each criterion depicted in a simple mathematical form; and
- The importance weights are incorporated into the comparison procedures.

This method is based on the concept that the chosen alternative should have the shortest distance to the Positive Ideal Solution (PIS) (the solution which minimizes the cost criteria and maximizes the benefit criteria), and the farthest distance from the Negative Ideal Solution (NIS). TOPSIS defines an indicator called similarity to the positive-ideal solution and remoteness from the negative-ideal solution. The fuzzy TOPSIS technique enables multi-criteria evaluation using linguistic values such as: very good, bad, average. They reflect the ambiguity and subjectivity of the assessment and are used when it is difficult to assign a precise attribute value to an alternative.

Chen (2006) extended TOPSIS with triangular FNs. He introduced a vertex method to calculate the distance between two triangular FNs: $\tilde{x}(a_1, b_1, c_1)$ and $\tilde{y}(a_2, b_2, c_2)$ as follows:

$$d(\tilde{x}, \tilde{y})\sqrt{\frac{1}{3}\left[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2\right]} \tag{6.1}$$

The current research uses a triangular fuzzy number for fuzzy TOPSIS because of the ease of calculating a triangular fuzzy number for decision-makers. Furthermore, it has been verified that modeling with triangular fuzzy numbers is an effective way of formulating decision problems where the information available is subjective and inaccurate (Rouhani at al., 2012).

6.2. Calculations of the Synthetic Indicator of Benefits Associated With the Implementation of the BI System in a Hospital

The presented example of the BI systems assessment for a hospital aims to create a ranking of six alternative solutions (A0–A5) depending on the subjective criteria related to the benefits of implementing a specific solution. The alternative marked as A0 is the approach to data analysis used so far and based on traditional office software. The others marked A1–A5 are the BI systems being considered. For the assessment of each variant, the authors of the study decided to assign a linguistic value from a five-element set identical to the case of criteria assessment (Figure 4): very low (VL), low (L), medium (M), high (H), very high (VH). The evaluation values obtained during the discussion panel for 6 alternative solutions (A0–A5) according to 15 criteria (F1–F15) are included in Table 3.

Table 3. Decision matrix using fuzzy linguistic variables

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15
A0	VL	L	L	VL	VL	L	L	L	L	L	L	L	VL	L	VH
A1	H	VH	H	M	M	L	M	M	H	H	VH	VH	M	H	M
A2	H	H	M	H	H	H	M	H	M	M	VH	H	H	M	M
A3	VH	VH	VH	H	H	VH	H	H	H	H	H	H	H	H	VL
A4	VH	H	H	H	M	H	M	H	M	H	H	M	M	M	L
A5	VH	H	H	H	M	H	VH	H	M	VH	VH	M	VH	H	M

Source: Authors' own elaboration.

The linguistic assessments obtained during the study were transformed according to membership functions in Figure 4 into a matrix of fuzzy numbers shown in Table 4. It also contains fuzzy numbers (FN) defining the weights of individual criteria assigned according to the test results presented in Table 1.

Table 5 shows the values of assessments of individual alternatives, including criteria weights.

The next step in the transformation of the test results according to the fuzzy TOPSIS technique is to define a fuzzy positive-ideal solution (FPIS, A^+) and a fuzzy negative-ideal solution (FNIS, A). FPIS and FNIS for the considered example of evaluation are presented in Table 6.

Table 4. Fuzzy decision matrix and fuzzy attribute weights

Criterion	F1	F2	F3	F4	F5
A0	(0.00; 0.10; 0.25)	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)	(0.00; 0.10; 0.25)	(0.00; 0.10; 0.25)
A1	(0.55; 0.70; 0.85)	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)
A2	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)
A3	(0.75; 0.90; 1.00)	(0.75; 0.90; 1.00)	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)
A4	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)
A5	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)
Weight	**(0.55; 0.70; 0.85)**	**(0.15; 0.30; 0.45)**	**(0.35; 0.50; 0.65)**	**(0.75; 0.90; 1.00)**	**(0.55; 0.70; 0.85)**

Criterion	F6	F7	F8	F9	F10
A0	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)
A1	(0.15; 0.30; 0.45)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)
A2	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)
A3	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)
A4	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)
A5	(0.55; 0.70; 0.85)	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.75; 0.90; 1.00)
Weight	**(0.35; 0.50; 0.65)**	**(0.35; 0.50; 0.65)**	**(0.15; 0.30; 0.45)**	**(0.55; 0.70; 0.85)**	**(0.35; 0.50; 0.65)**

Criterion	F11	F12	F13	F14	F15
A0	(0.15; 0.30; 0.45)	(0.15; 0.30; 0.45)	(0.00; 0.10; 0.25)	(0.15; 0.30; 0.45)	(0.75; 0.90; 1.00)
A1	(0.75; 0.90; 1.00)	(0.75; 0.90; 1.00)	(0.35; 0.50; 0.65)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)
A2	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)
A3	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.55; 0.70; 0.85)	(0.00; 0.10; 0.25)
A4	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)	(0.35; 0.50; 0.65)	(0.15; 0.30; 0.45)
A5	(0.75; 0.90; 1.00)	(0.35; 0.50; 0.65)	(0.75; 0.90; 1.00)	(0.55; 0.70; 0.85)	(0.35; 0.50; 0.65)
Weight	**(0.35; 0.50; 0.65)**	**(0.35; 0.50; 0.65)**	**(0.55; 0.70; 0.85)**	**(0.15; 0.30; 0.45)**	**(0.00; 0.10; 0.25)**

Source: Authors' own elaboration.

Table 5. Fuzzy-weighted decision matrix

Criterion	F1	F2	F3	F4	F5
A0	(0.00; 0.07; 0.21)	(0.02; 0.09 0.20)	(0.05; 0.15; 0.29)	(0.00; 0.09; 0.25)	(0.00; 0.07; 0.21)
A1	(0.30; 0.49; 0.72)	(0.11; 0.27 0.45)	(0.19; 0.35; 0.55)	(0.26; 0.45; 0.65)	(0.19; 0.35; 0.55)
A2	(0.30; 0.49; 0.72)	(0.08; 0.21 0.38)	(0.12; 0.25; 0.42)	(0.41; 0.63; 0.85)	(0.30; 0.49; 0.72)
A3	(0.41; 0.63; 0.85)	(0.11; 0.27 0.45)	(0.26; 0.45; 0.65)	(0.41; 0.63; 0.85)	(0.30; 0.49; 0.72)
A4	(0.41; 0.63; 0.85)	(0.08; 0.21 0.38)	(0.19; 0.35; 0.55)	(0.41; 0.63; 0.85)	(0.19; 0.35; 0.55)
A5	(0.41; 0.63; 0.85)	(0.08; 0.21 0.38)	(0.19; 0.35; 0.55)	(0.41; 0.63; 0.85)	(0.19; 0.35; 0.55)
Criterion	F6	F7	F8	F9	F10
A0	(0.05; 0.15; 0.29)	(0.05; 0.15; 0.29)	(0.02; 0.09; 0.20)	(0.08; 0.21; 0.38)	(0.05; 0.15; 0.29)
A1	(0.05; 0.15; 0.29)	(0.12; 0.25; 0.42)	(0.05; 0.15; 0.29)	(0.30; 0.49; 0.72)	(0.19; 0.35; 0.55)
A2	(0.19; 0.35; 0.55)	(0.12; 0.25; 0.42)	(0.08; 0.21; 0.38)	(0.19; 0.35; 0.55)	(0.12; 0.25; 0.42)
A3	(0.26; 0.45; 0.65)	(0.19; 0.35; 0.55)	(0.08; 0.21; 0.38)	(0.30; 0.49; 0.72)	(0.19; 0.35; 0.55)
A4	(0.19; 0.35; 0.55)	(0.12; 0.25; 0.42)	(0.08; 0.21; 0.38)	(0.19; 0.35; 0.55)	(0.19; 0.35; 0.55)
A5	(0.19; 0.35; 0.55)	(0.26; 0.45; 0.65)	(0.08; 0.21; 0.38)	(0.19; 0.35; 0.55)	(0.26; 0.45; 0.65)
Criterion	F11	F12	F13	F14	F15
A0	(0.05; 0.15; 0.29)	(0.05; 0.15; 0.29)	(0.00; 0.07; 0.21)	(0.02; 0.09; 0.20)	(0.00; 0.09; 0.25)
A1	(0.26; 0.45; 0.65)	(0.26; 0.45; 0.65)	(0.19; 0.35; 0.55)	(0.08; 0.21; 0.38)	(0.00; 0.05; 0.16)
A2	(0.26; 0.45; 0.65)	(0.19; 0.35; 0.55)	(0.30; 0.49; 0.72)	(0.05; 0.15; 0.29)	(0.00; 0.05; 0.16)
A3	(0.19; 0.35; 0.55)	(0.19; 0.35; 0.55)	(0.30; 0.49; 0.72)	(0.08; 0.21; 0.38)	(0.00; 0.01; 0.06)
A4	(0.19; 0.35; 0.55)	(0.12; 0.25; 0.42)	(0.19; 0.35; 0.55)	(0.05; 0.15; 0.29)	(0.00; 0.03; 0.11)
A5	(0.26; 0.45; 0.65)	(0.12; 0.25; 0.42)	(0.41; 0.63; 0.85)	(0.08; 0.21; 0.38)	(0.00; 0.05; 0.16)

Source: Authors' own elaboration.

Table 6. Fuzzy positive- and negative-ideal solution (FPIS & FNIS)

	F1	F2	F3	F4	F5
A^+	(0.41; 0.63; 0.85)	(0.11; 0.27; 0.45)	(0.26; 0.45; 0.65)	(0.41; 0.63; 0.85)	(0.30; 0.49; 0.72)
A^-	(0.00; 0.07; 0.21)	(0.02; 0.09; 0.20)	(0.05; 0.15; 0.29)	(0.00; 0.09; 0.25)	(0.00; 0.07; 0.21)
	F6	F7	F8	F9	F10
A^+	(0.26; 0.45; 0.65)	(0.26; 0.45 0.65)	(0.08; 0.21; 0.38)	(0.30; 0.49; 0.72)	(0.26; 0.45; 0.65)
A^-	(0.05; 0.15; 0.29)	(0.05; 0.15 0.29)	(0.02; 0.09; 0.20)	(0.08; 0.21; 0.38)	(0.05; 0.15; 0.29)
	F11	F12	F13	F14	F15
A^+	(0.26; 0.45; 0.65)	(0.26; 0.45; 0.65)	(0.41; 0.63; 0.85)	(0.08; 0.21; 0.38)	(0.00; 0.09; 0.25)
A^-	(0.05; 0.15; 0.29)	(0.05; 0.15; 0.29)	(0.00; 0.07; 0.21)	(0.02; 0.09; 0.20)	(0.00; 0.01; 0.06)

Source: Authors' own elaboration.

$$\tilde{A}^{+} = \left\{\widetilde{v_1}^{+}(x), \widetilde{v_2}^{+}(x), \ldots, \widetilde{v_J}^{+}(x), \widetilde{v_{15}}^{+}(x)\right\}\left\{\max_i \widetilde{v_J}(x) \,\middle|\, i = 0, \ldots, 5\right\} \quad (6.2)$$

$$\tilde{A}^{-} = \left\{\widetilde{v_1}^{-}(x), \widetilde{v_2}^{-}(x), \ldots, \widetilde{v_J}^{-}(x), \widetilde{v_{15}}^{-}(x)\right\}\left\{\min_i \widetilde{v_J}(x) \,\middle|\, i = 0, \ldots, 5\right\} \quad (6.3)$$

where:
$\widetilde{v_{ij}}$ is a weighted assessment of the alternative *Ai* according to the criterion *Fj*.

The last step of the transformation is to calculate, for each alternative (A0–A5), the distances from FPIS and FNIS according to the relationship (6.1) and to calculate the synthetic measure of similarities to the ideal solution (C), which is treated as a synthetic indicator of the benefits of implementing a specific BI system in UCHiO.

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (6.4)$$

Detailed calculations for FC_{A0} similarities to an ideal solution are as below:

$$d_{A0}^{+} = \sqrt{\frac{1}{3}\left[(0.41 - 0)^2 + (0.63 - 0.07)^2 + (0.85 - 0.21)^2\right]} + \\ + \sqrt{\frac{1}{3}\left[(0.11 - 0.02)^2 + (0.27 - 0.09)^2 + (0.45 - 0.2)^2\right]} + \ldots + \\ + \sqrt{\frac{1}{3}\left[(0 - 0)^2 + (0.09 - 0.09)^2 + (0.25 - 0.25)^2\right]} = 1.715$$

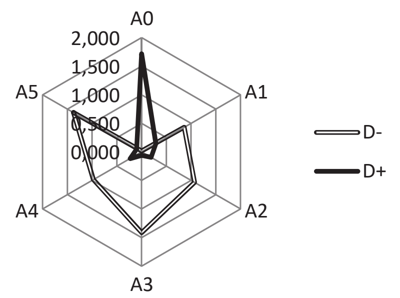
$$d_{A0}^{-} = \sqrt{\frac{1}{3}\left[(0 - 0)^2 + (0.07 - 0.07)^2 + (0.21 - 0.21)^2\right]} + \\ + \sqrt{\frac{1}{3}\left[(0.02 - 0.02)^2 + (0.09 - 0.09)^2 + (0.2 - 0.2)^2\right]} + \ldots + \\ + \sqrt{\frac{1}{3}\left[(0 - 0)^2 + (0.09 - 0.01)^2 + (0.25 - 0.06)^2\right]} = 0.014$$

$$C_{A0} = \frac{0.014}{1.715 - 0.014} = 0.008$$

The results of the calculations of the synthetic indicator of the benefits assessment of the implementation of alternative BI systems are summarized in Table 7. Their graphic interpretation as distances of individual alternatives to FPIS and FNIS is also presented.

Table 7. Final results of fuzzy TOPSIS analysis of BI systems for UCHiO

	d^+	d^-	FC
A0	1.715	0.014	**0.008**
A1	0.288	0.859	**0.749**
A2	0.190	1.068	**0.849**
A3	0.062	1.415	**0.958**
A4	0.234	0.974	**0.807**
A5	0.100	1.376	**0.932**

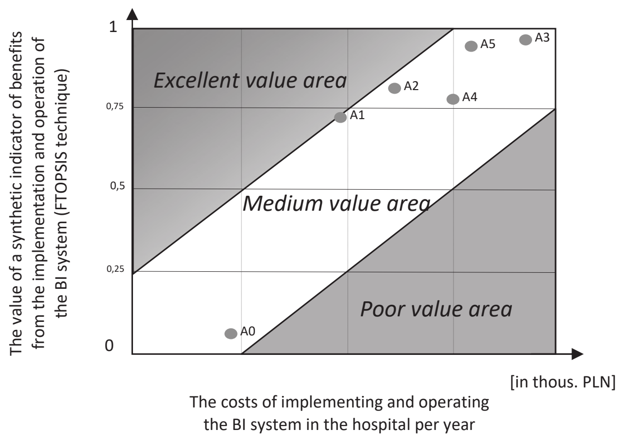


Source: Authors' own elaboration.

6.3. Evaluation of BI Systems Depending on Benefits and Costs

When deciding to implement a BI system, its value should be taken into account by analyzing the expected benefits and costs. Therefore, it is necessary to evaluate systems according to both sets of criteria presented in Table 1 and Table 2. For this purpose, a map of the BI system values for the hospital, shown in Figure 5, has been proposed. Such visualization makes it possible to look at the assessed set of solutions from the perspective of benefits and costs for such a unit as UCHiO, i.e. the value of the BI system for a specific recipient.

Figure 5. Evaluation map for the value of BI systems for UCHiO



Source: Authors' own elaboration.

The positions of alternative solutions A0–A5 are presented on the map. The ones that are closest to the top left corner of the map are recommended in the area marked as "excellent value area". In contrast, solutions located in the area close to the bottom right corner of the map should be rejected. When evaluating BI systems for UCHiO, it should be assumed that the closer the solution is to the upper left corner of the map, the higher its value for the recipient and the higher position in the ranking. The proposed method of visualization is intended as a support in making complex analyses for the needs of managerial decisions. The following conclusions have been formulated for the set of solutions in Figure 5.

(1) The solution closest to the "poor value area" is that marked A0, i.e. the one used so far, based on reports prepared in spreadsheets. Therefore, the manager should decide on a change.

(2) The solution of the highest value is that marked A1, which was rated as the least favorable by experts among the considered BI systems.

(3) The price negotiations with the suppliers of systems marked A2 and A5 will have the greatest importance for the final decision on the selection of the system. The elements that comprise financing of these solutions should be analyzed (Table 2) and business negotiations with the suppliers should be conducted.

(4) Solution A3, which was indicated by the experts as the most advantageous, lost its position after taking into account the costs. Its value after taking into account the costs turned out to be average.

7. Conclusions

The article presents the methodology of BI systems evaluation which was developed for the needs of UCHiO. Its characteristic feature is the assessment of benefits from the perspective of the needs of a specific organization. It differs from the assessments of BI systems made by consulting companies such as Gartner. The approach to evaluation proposed in the article requires establishing a set of criteria dedicated to a hospital. In the case of other organizations such as enterprise, university or public institution, this set of criteria would have to be different, adapted to their specificity. The key role of the selection of criteria and their weights should be emphasized here. They must be associated with strategic goals and reflect their importance for the development of the organization. The benefits of implementing BI systems can be assessed only on the basis of subjective criteria requiring the acquisition of expert knowledge. Determination of precise values based on the activities of a similar organization is unjustified and leads to the adoption of erroneous assumptions. Due to the ambiguity of the information which can be obtained, the authors decided to use the assessment in the linguistic form. The assessments were then aggregated into a synthetic indicator of the benefits of implementing BI systems using the fuzzy TOPSIS technique. In order to decide on the choice of a particular BI system, a map was proposed making it possible to analyze alternative solutions both in terms of benefits and costs. The original elements of the article are the criteria for assessing the benefits of implementing BI systems for hospitals and the method of evaluation of BI systems based on the fuzzy TOPSIS technique, verified in a practical example. The approach presented in the article is of particular practical importance for entities financed from public funds, when expenses incurred must be clearly justified. An important functionality of the proposed methodology is also enabling the decision-maker to compare BI systems in the situation of imprecise data and incomplete information. This purpose is served by a synthetic indicator of benefits from the implementation of BI systems, as well as the visualization of the value of the solutions shown in the proposed map. However, at this point, the limitations of methods related to expert assessment should be indicated. Finding one expert who has knowledge of all the analyzed solutions is difficult or even impossible in practice. In the example presented in the article, a panel of experts was used. They exchanged their knowledge about BI systems with which they had contact and on this basis they made a linguistic evaluation. However, it is essential and difficult to find a common reference point for assessments by different people. This can lead to a situation when a milder opinion of one expert gives an unjustified advantage to a particular BI system. The conducted evaluation confirmed the usefulness of the proposed methodology. However, it should also be verified in other types of organizations. The use of fuzzy AHP technique and a comparison of the results obtained are also taken into consideration.

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