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MULTI-CRITERIA COMPARATIVE ANALYSIS OF GIS CLASS SYSTEMS

Abstract: The article discusses a multi-criteria comparative analysis of GIS class computer systems using the Pareto method . Referring to this problem, to find a GIS system (a compromise solution) that would be acceptable for each decision criterion, to make a Pareto optimal decision, multi-criteria optimization was obligatory. To find the mentioned optimum (the Pareto optimum), it is necessary for the decision maker to make a choice concerning the set of admissible decision solutions. Here, a matrix of criteria constructed by the authors is available, filled in with appropriate weights by field experts. This structure is very useful when evaluating the admissible solutions of the resulting algorithm. The space of acceptable solutions in the considered problem task is a set of systems, limited to their eighteen instances, which meet the criterion of completeness of all data required in the conducted research. The selected criteria are the most widely used and most accepted in the environments that systems of this class use daily.

Keywords: GIS, multi-criteria optimization, ideal point, space of admissible solutions

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Introduction

We are witnessing technological progress and the development of individual fields of knowledge, which imply a huge technological leap in the constant road to perfection. Both information technologies and all emerging innovations are ultimately intended to serve man in the implementation of his daily tasks and duties, making his work easier and more efficient in implementation geoinformation technology patterns and shows how GIS technology can best meet business needs (Fig. 1).

Fig. 1. GIS technology has evolved to support a wide integrated range of business needs across the organization
Source: http://wiki.gis.com/wiki/index.php/System_Implementation

GIS systems have already perfectly integrated into today's reality and the concept of enterprise 2.0 (e.g. *high technology, knowledge management*), and the degree of their integration with organizations in the current economic reality makes them not only an indicator of success on the market, but eo ipso (*eo ipso* in translation from Latin means: *the same, as a result, as a result)* also an inseparable element of any modern business organization.

The purpose of this article is to present a multi-criteria comparative GIS analysis that enables the selection of a properly tailored and effective GIS solution for a given enterprise. The problem is not trivial; hence this work presents its own way of thinking and several techniques that can help the decision maker in making effective decisions. It is important and repeatedly emphasized that all the techniques described in this article are universal and can be applied to almost any problem that you can currently encounter.

The results obtained by means of multi-criteria optimization in the PARETO sense can and very often constitute a kind of help, guidance and advice in decision-making, however, one should not base one's choice solely on them. As indicated at the research stage, these methods are characterized by high sensitivity (sensitivity) to data, and their proper implementation is associated with the meticulousness, knowledge and precision of the researcher.

This article consists of six sections. The first section covers assumptions and key concepts. The second section contains the results of the literature review, based on which the types and categories of GIS were specified and then characterized for the purposes of comparative analysis. The third section presents the research methodology. The fourth section contains information on the problem analysis and research results. Finally, section five describes the conclusions and recommendations.

Assumptions and key concepts

GIS is a technology rooted in geographic informatics that allows users to delve into geospatial data . GIS programs require both hardware and software, such as the desktop needed to display information.

GIS helps users make more informed decisions. When working with a physical location, you need to understand every aspect of it – air, land, water, surroundings, and more. The GIS captures this array of data, detailing various aspects of the landscape, and stores them all in one platform.

GIS software is used to deploy GIS functionality and business logic where it is needed – on desktops, servers, custom applications, web services and mobile devices. GIS applications are supported by a common set of software components. Figure 2 shows the ArcGIS cloud-based architecture. Figure 2 shows how GIS architecture is evolving to enable more adaptive and functional exchange of geographic information.

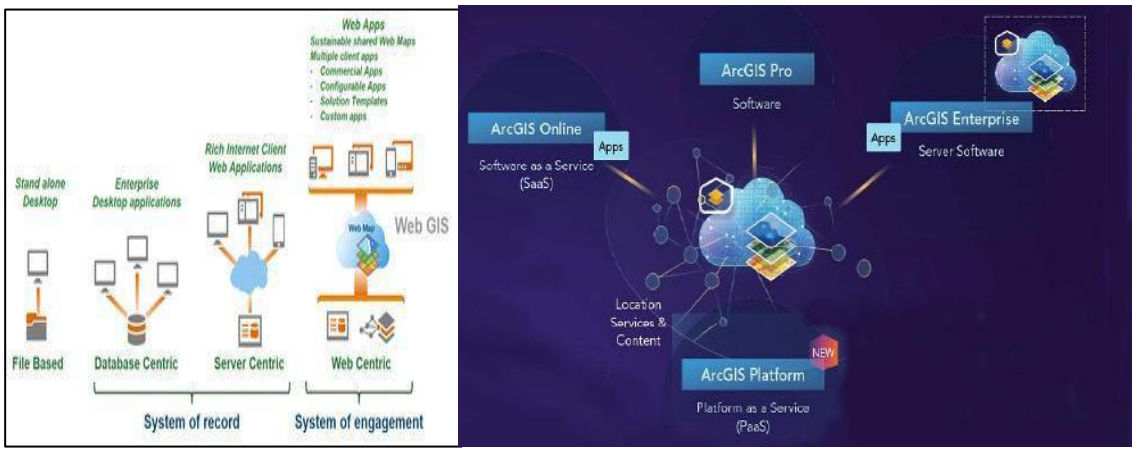


Fig. 2. GIS architectural patterns have evolved from standalone single-user desktop file-based systems to more collaborative Web GIS systems
Source: own study

Table 1 presents a brief description of selected GIS architecture patterns available in the professional literature.

Table 1. Notable Patterns of GIS Architecture

Template	**Description** [literature]
File based systems:	Desktop apps that created file-based datasets that were unique to a given user. Building and sharing information was limited to individual relationships, and data integration was limited. (Chang & Kang-tsung, 2016; Fu & Sun, 2010; Marler & Arora, 2004)
Database orientation:	Enterprise Desktop customers would access a centrally shared geodatabase data source . The data was maintained and made available in an integrated database environment, improving the continuity of information and the quality of available data resources. Published data can be managed and controlled to promote a common view of available verified data resources. Access to data resources was limited to desktop users in the local network. (Goodchild, 2010; Marler & Arora, 2004; Xuan & Zhu, 2016)
Server orientation :	Database resources were published as Web services, making information products available to a wide Internet community of Web clients. Rich Internet clients can access services from multiple server locations, extending access and integration of information resources to a much wider community of users. Applications have been developed and deployed to take advantage of available Internet services. *Best practice: Database and server-oriented architecture patterns provide optimal record content system management.* (DeMers, 2009; Miłek et al., 2023a; Saaty, 2012)
Network Oriented:	The introduction of the portal architecture has expanded web content development for the business community, no longer requiring the design effort of developers to implement new web information products. General commercial applications with the ability to leverage web maps created and shared by business users provide quick access to information products anywhere and on any supported device. Users can create and administer their own groups to share content, use customizable apps to build new web apps, and use solution templates to quickly create and deploy content to a wide user community. *Best practice: The web portal architecture provides the optimal solution for the engagement system.* (Bolstad, 2019; Maliene et al., 2011; Mironova, 2020)
Focus on cloud solutions:	With the shift to networking and cloud computing, and integration with real-time information via the Internet of Things, GIS has become a vital platform for almost every human endeavor – the nervous system of the planet. As our world faces issues of increasing population, loss of nature and pollution, GIS will play an increasingly important role in how we understand and solve these problems and provide the means to communicate solutions using a common mapping language. (Miłek et al., 2023b; Peuquet & Marble, 1990; Somers, 1996)

Source: own study

Optimization is an engineering discipline that seeks extreme values of design criteria. However, quite often there are many conflicting criteria that need to be resolved. One of these criteria is met at the expense of another. In the literature, multi-

criteria decision making (MCDM) and optimization approaches have been used in various ways. The problem with MCDM methods is generally a selection problem where one tries to select the best or optimal alternative from a predetermined but finite set of alternatives. The choice of a particular MADM method depends on the characteristics of the problem and is also partly based on the preferences of the decision maker. Two approaches can be used to solve MADM problems with a homogeneous data type. First, the data can only be treated to form a set of uniform input parameters, and classical MADM methods can be used to solve the problem. Second, the MADM methods should be modified to accept mixed input parameters. Both approaches should lead to the same result, but the first seems to be simpler and more effective (Chen & Hwang, 1992). In recent literature, common MADM methods include the simple weighted addition (SWA) method, the analytic hierarchical process (AHP) and various lookahead methods such as reality translating elimination and selection (ELECTRE). AHP was developed by Saaty (Saaty, 1980). A multi-criteria problem begins when a decision maker has a situation that requires a decision (Ameljańczyk, 1984). There are a number of criteria that should be addressed by the decision maker, and several different courses of action may be available to address most or all of the criteria in some way. The problem faced by the decision-maker is to determine which course of action or alternative would best meet the criteria and fully meet the constraints (Rao & Davin, 2008; Zimmermann, 1991).

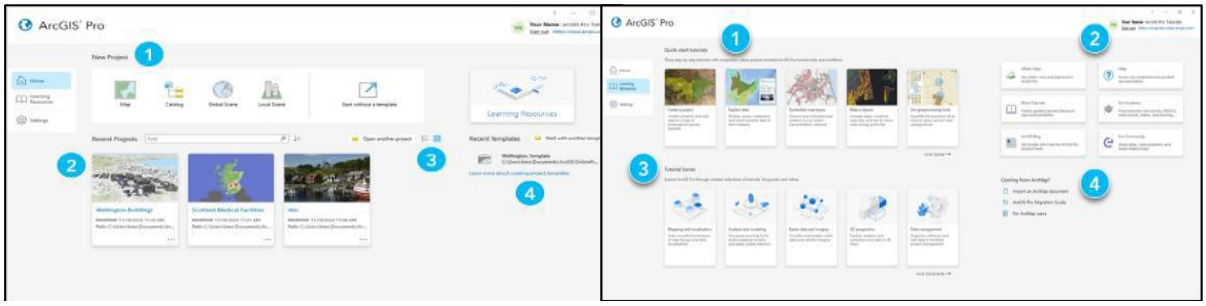
Review of the studied GIS systems

There are plenty of GIS systems on the market, designed for a wide range of applications. Many of the offered solutions come from various domestic and foreign companies. To illustrate the number of foreign players and market tycoons, a summary in the form of the Gartner magic quadrant was presented (Fig. 3).

Fig. 3. GIS class solutions for small and medium enterprises
Source: own study

Bearing in mind the limitations regarding the volume of the article, only six systems will be characterized in this subchapter: ArcGIS Pro, WebGIS, BatchGeo, Google Earth Pro, MAPTITUDE, ArcGIS Desktop application. Other GIS can be found in studies (Miłek et al., 2023a & 2023b; Peuquet & Marble, 1990; Somer, 1996).

ArcGIS Pro is a full-featured professional desktop GIS application from Esri . With ArcGIS Pro, you can explore, visualize, and analyze data; create 2D maps and 3D scenes; and share your work to ArcGIS Online or your ArcGIS Enterprise portal. The sections below introduce the sign-in process, the start page, ArcGIS Pro projects, and the user interface. ArcGIS Pro is tightly coupled with the ArcGIS platform for sharing data with ArcGIS Online and ArcGIS Enterprise through Web GIS. ArcGIS Pro is a next-generation 64-bit GIS application that offers professional 2D and 3D mapping tools in an intuitive user interface. ArcGIS Pro accelerates data visualization, analysis, image processing, management, and integration. ArcGIS is a GIS mapping software that provides a platform for map creation and analysis of captured geographic data. ArcGIS can be used as a standalone application and combined with others to support location mapping. It is helpful in working with a set of analytical data and spatial algorithms. ArcGIS programming is useful in monitoring the location of any type of sensor or device. Official screenshots:



Basic functions:
ArcGIS extends some of its unique potential with flexible licenses to apply location-based analytics to any business practice. Provides insights for data visualization and analysis, and data sharing in the form of maps, dashboards, reports, and more. ArcGIS Pro supports data visualization, advanced analytics, and reliable data handling in both 2D and 3D. functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation, data visualization.

Map creation:

- Geocoding.
- Buffer zone query.
- Overlay.

- Publishing.

Analysis:

- Spatial analysis.
- Reporting,.
- Real-time streaming.
- Distance analysis.
- Spatial analysis.

Cartography:

- Map design.
- Data visualization.

Pros:

- Can be easily used for a variety of jobs such as changing slope, aspect, etc.
- It is very user friendly.
- Unified 3D Integration.
- Clear cartography and labeling.
- True integration with ArcGIS Online.
- Contextual smart ribbon interface.
- 64-bit processing.
- Improved and intuitive editing.
- Geospatial analysis.

Minuses:

- High license cost.
- Project files are bulky.
- The MXD conversion skips all objects.
- Assign licenses through ArcGIS Pro.
- High learning curve.

WebGIS. The web app includes built-in tools to create 2D and 3D web apps for job and branding tasks. It is user-friendly, flexible and full of GIS features. The WebGIS application can be used by any user, at any time and on any device. Maps, apps, analytics, data management, collaboration - you can do it all with ArcGIS Online. You can use ArcGIS Online as an integral part of ArcGIS to extend the capabilities of ArcGIS Desktop, ArcGIS Enterprise, ArcGIS Web APIs, and ArcGIS Runtime SDKs. It can also be used as a standalone Web GIS.

WebGIS is quite fast and efficient for setting up web applications that are visually appealing and useful to non-GIS users. Once they're set up, they should be able to run with relatively little effort on my part and save me time to focus on other priority projects. Official screenshots:

Basic functions:

The program is equipped with typical GIS functions. Its features are incomparable to simple mapping solutions, yet very intuitive for everyone throughout the organization and beyond. Developers can create custom widgets and themes to extend ArcGIS Web AppBuilder. Functional range incl. includes:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Cartography:

- Map design.
- Vector mapping.
- Data visualization.
- Overlaying.

Advantages:

- Web AppBuilder is a great tool for building custom and customizable apps.
- You can get a relatively easy application in a few minutes.
- It is easy to import data into it and create a completely new application.
- The adaptability between different layers and designs makes it even more promising.

Defects:

- The UI is not very user friendly and the documentation is poor in some parts.
- ESRI Living Atlas data in the Add Data panel, making it difficult to focus and view only internally created data instead of searching with keywords.
- No custom widgets.

BatchGeo. BatchGeo is software that allows you to paste location data to map them. This is one way to create Google Maps with your data. Just copy the data, validate and set options, then map the locations. The result is a colorful, information-rich map where you can easily visualize spreadsheet information. BatchGeo is also the easiest way to get a list of addresses on a map.

BatchGeo since 2006 hosts millions of maps for Fortune 50 companies , nonprofits, and individuals. The idea behind BatchGeo is that most geographic data is stored in a spreadsheet, list, or simple table (e.g. Excel, CSV, Google Spreadsheets, etc.) It is optimized for these formats, making it very easy to drag or copy/paste data tabular on the map. Official screenshots:

Basic functions:

The program is equipped with typical GIS functions.

Functional range incl. includes:

Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Advantages:

- BatchGeo is a leader in the mapping category.
- BatchGeo is extremely easy to use - the user interface is very intuitive.
- You can easily create regional maps or projects in a few simple steps.
- You can easily and quickly create a map using the data in an Excel file.

Defects:

- Some reporting features are missing for further analysis of geocoded batch addresses.
- If you make a mistake, it's hard to go back and make changes.

Google Earth Pro. Google Earth Pro is a powerful and feature-rich tool for exploring the world and visualizing geographic data. It can import and analyze large amounts of data, including vector and raster images, 3D models and GIS data. The software also allows me to measure distances, create custom maps and visualizations, and export high-quality photos and videos. Overall, Google Earth Pro is an extremely versatile and user-friendly application that offers a wealth of tools for anyone interested in exploring and understanding our planet.
Official screenshots:

Basic functions:
Overall, Google Earth Pro is an extremely versatile and user-friendly application with the following functional scope:
Data management:

- Data capture.
- Data storage.
- Data manipulation.
- Data visualization.

Creating a map:

- Geocoding.
- Buffer zone query.
- Overlaying.
- Publishing.

Analysis:

- Spatial analysis.
- Reporting.
- Real-time streaming.

Advantages:

- Google Earth pro is the best service to explore different regions of the whole earth.
- Easy, convenient and simple to use mapping tool.
- The best tool for accessing geolocation and maps.
- The best virtual roaming tool around the world.

Defects:

- Quite demanding in terms of required computing power.
- Some remote areas are off-limits to high-resolution photos.
- There is no easy way to store your personal pins , placemarks, starting points, etc. in the cloud – you must go through the entire registry to make these changes.

Maptitude. Maptitude is one of the best mapping software on the market with the richest set of features and the highest performance. Full-featured mapping software. It is one of the GIS mapping programs that provides tools, maps and demographics that are useful for visualizing data by discovering geographical patterns from the available data and presenting the data in a more elementary way. Maptitude offers the benefits of desktop mapping and spatial analysis in one easy-to-use package. With Maptitude, you can easily and efficiently create maps and map images from spreadsheets. You can import external data into your map from various sources, including Google Maps KML/KMZ files . Official screenshots:

Basic functions:

Maptitude is designed for data visualization and geographic analysis. Some of its best and enhanced features include creating and editing maps, adding data to maps, analyzing data. functional scope:

Data management:

- Data capture.
- Data storage.

- Data manipulation.
- Data visualization.

Create a map:

- Geocoding.
- Overlaying.

Spatial analysis:

- Reporting.
- Data visualization.

Advantages:

- The most efficient and cheapest.
- Ease of use.
- High quality support.
- Ease of setup.

Defects:

- Less community supports.
- Archaic cartography and symbolism.
- Dated 3D rendering with NASA World Wind.
- Little about metadata standards.
- Little support for LiDAR data.
- No cross-platform mobile data collection.
- Adding data without geometry icons.

ArcGIS Desktop app. An integrated collection of GIS software. It provides a standards-based platform for spatial analysis, data management and mapping. ArcGIS Desktop is the latest in GIS. It raises the bar to the next level by doing what other GIS software can't. Its success lies in the fact that it can be expanded. From field applications to modeling and scripting, ArcGIS Desktop is a powerhouse for all GIS systems. ArcGIS Desktop is a tool that allows you to create, analyze, share and manage geographic information in such a way as to support decision makers in making optimal business decisions based on collected and developed data. Using data from multiple sources, ArcGIS Desktop allows you to create intelligent and visually attractive maps, identify spatial patterns, and share information depending on the purpose, in the organization, on the Internet or in mobile applications. Official screenshots:

Basic functions:
ArcGIS Desktop is a tool that allows you to create, analyze, share and manage geographic information. functional scope:

- Advanced analytics – has analytical tools to identify relationships and patterns, their changes over time, as well as forecasting and answering key business questions.
- Image processing – provides advanced tools for managing and analyzing images from drones, satellites, lidar data and more.
- Advanced visualization – it is possible to use advanced cartographic tools to visualize data on interactive maps.
- Sharing – share maps on the Internet and integrate them with other systems.
- Data Management – Ensures data integrity and accuracy with a complete set of tools for storing, editing, evaluating and managing all types of spatial information.

Advantages:

- ArcGIS Desktop is an easy-to-use and user-friendly GIS tool.
- Scalability for additional capabilities.
- Robust geoprocessing framework.
- Beautiful options for cartography symbolism.
- Full set of editing and topology tools.
- ArcGIS Online for web and app maps.

Defects:

- High use and maintenance costs.
- License levels provide limited tools to the basics.
- Poor performance on interoperability.
- Retiring ArcGIS Pro.
- 32-bit application from ArcCatalog.

Methodology

As already mentioned, the purpose of this article is to conduct, using the formal method, which is multi-criteria Pareto optimization, a comparative characteristic of GIS class information systems, intended for various entities of operation. Due to the large number of GIS systems on the market, it is impossible to obtain information about all products. Therefore, for the purpose of comparison, the following rules have been defined, according to which the solutions operating on the market will be classified into the set of compared systems:

- the system selection criteria were tailored to the needs of the small and medium-sized enterprise (SME) sector,
- source systems, but to be a true GIS, the system must contain a significant group of components (Table 2).

Table 2. Basic GIS components

Name	**A brief description of the component**
Spatial databases and attribute databases	The central element of the system is the database - a collection of maps and related information in digital form. Since the database deals with the features of the earth's surface, it consists of two elements – a spatial database describing the geography (shape and location) of the earth's surface features, and an attribute database describing the features or characteristics of these features.
Cartographic display system	We have several software components around the central database. The most basic of these is the cartographic display system, which allows you to download selected database items and generate output maps on a screen or paper device such as a printer or plotter.
Map digitization system	After the cartographic display, the next most important element is the map digitization system, which is used to convert existing paper maps into digital form. Map digitization can be done using scanning devices.
Database management system	Another logical component in GIS is a database management system (DBMS). GIS typically includes not only a traditional DBMS, but also a variety of tools to manage the spatial and attribute components of stored geographic data. With a DBMS, it is possible to enter attribute data such as tabular information and statistics, then extract specialized tables and statistical summaries to provide new tabular reports.
Image processing system	In addition to the essential elements of the GIS described above, some software systems also include the ability to analyze remotely sensed images and provide specialized statistical analysis. This is a significant component of the system as computer-aided interpretation of remote sensing data can be an important data acquisition technique, particularly in developing countries where current maps of many features are not available.
Statistical Analysis System	For statistical analysis, GIS must offer both traditional statistical procedures and some specialized spatial data analysis procedures.

Source: own study

In a series of studies, a comprehensive set of selected eighteen GIS class systems was subjected to a detailed analysis. Heuristic techniques were used, which allowed the estimation of individual parameters, determination of their significance function as well as the ranking and classification of the considered set of objects. The following concept of conduct was adopted in the study. Comparison criteria and rules for the selection of GIS systems for comparison were defined. Then, factors were specified, which, based on the research and experience, are considered critical in the process of selection and implementation of appropriate GIS class solutions. In the next step, the most important selection criteria were defined – the selection of systems, and on their basis a summary and comparative analysis of GIS systems will be carried out. Eight thematic groups of criteria were used in the research, based on which the selection of GIS solutions for comparison was carried out. The adopted comparative criteria have been presented in a hierarchical form, grouped into appropriate thematic classes using a mind map scheme (Fig. 4):

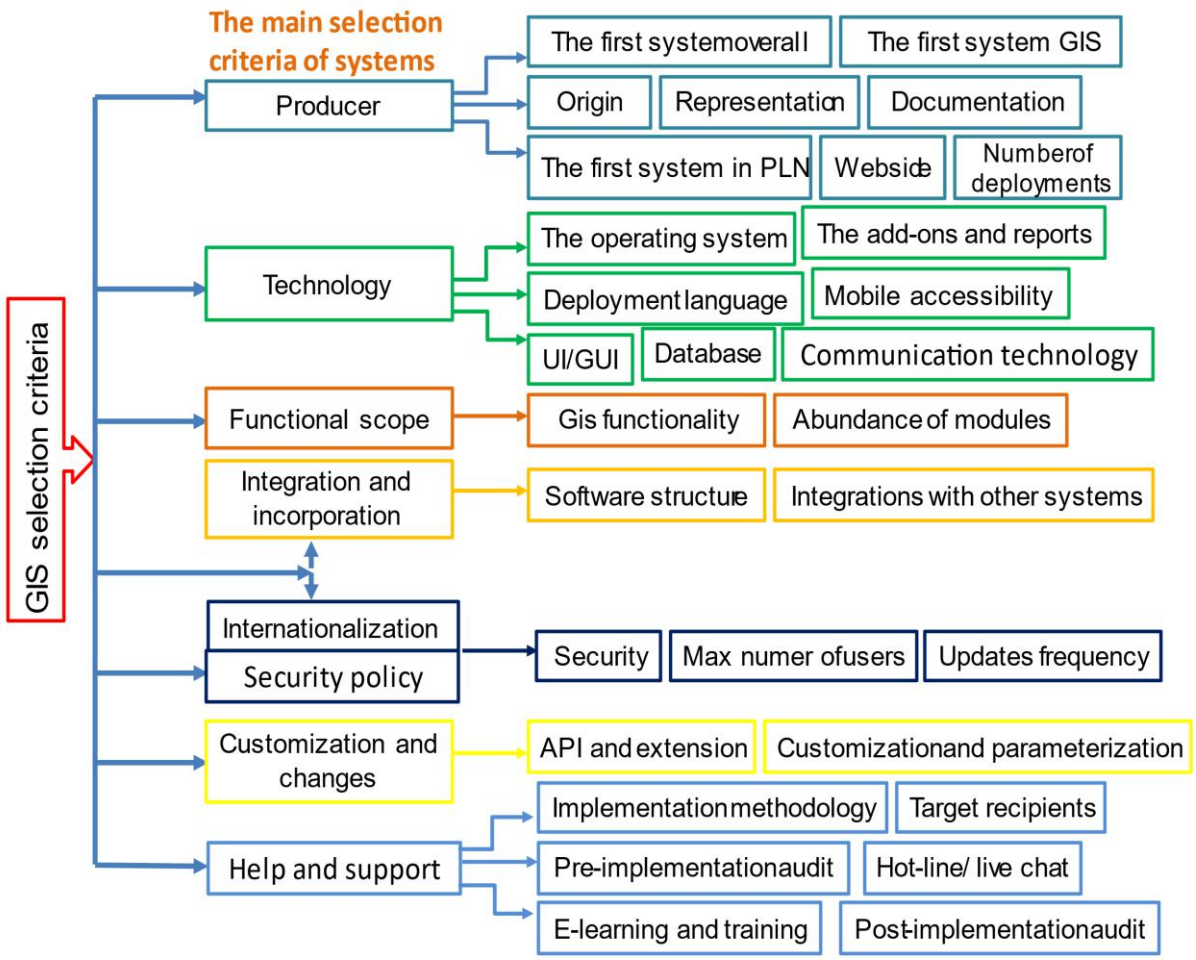


Fig. 4. Hierarchical structure of the ERP system selection problem tree
Source: own study

The comprehensive characterization was carried out based on a number of experiences, interviews and information obtained from many different sources, ranging from periodicals and industry literature with a high eigenfactor, to websites and consultations with system manufacturers. However, environmental conditions made companies reluctant to share any information about their products. Most of the data was very general.

The final step of the undertaken network of actions is to determine the exact distance that separates each of the tested GIS class systems from the set ideal point.

Results and discussion

In order to find the optimum (Pareto optimum), it is necessary for the decision maker to make a choice concerning the set of admissible decision solutions. Here you have a self-constructed matrix of criteria, filled with appropriate weight values by domain experts. This structure will be very useful when evaluating admissible solutions of the resulting algorithm. The space of acceptable solutions in the considered problem is a set of GIS systems, limited to their eighteen instances.

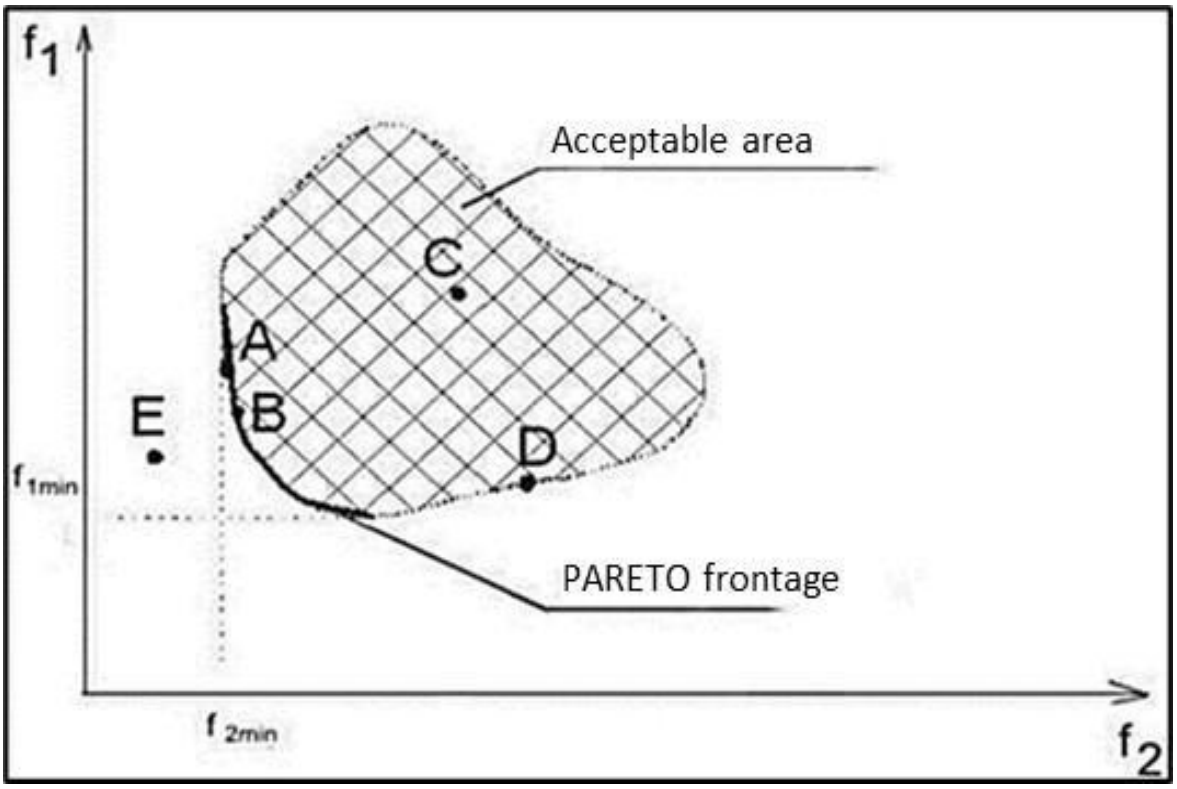


Fig. 5. A visual, graphical representation of Pareto- optimal decision solutions
Source: own study

On the axes of the coordinate system there are selected quality indicators, while the filled space is mapped to the decision space. The indexes A, B, C, D have marked the individual elements constituting the solution. The point located in the closest distance to the optimum, lying on the Pareto front, is optimal. The area of the Pareto front is a space of non-dominated solutions and at the same time it creates a set of solutions that are optimal from Pareto's point of view (Fig. 5).

Starting to determine the set of acceptable solutions, we decided to evaluate the considered GIS systems using the Delphi method in accordance with the algorithm presented in Fig. 6. Collecting the individual assessments of decision-makers and field experts, the range of assessment functions from one to nine was adopted (analogous to the AHP method, which is presented in (Saaty, 2012). An increase in weight means a greater importance of the considered feature. The final matrix showing the comparison of solutions from the considered set of GIS systems and their degree of fulfillment of a given feature (criterion) is presented in table 3.

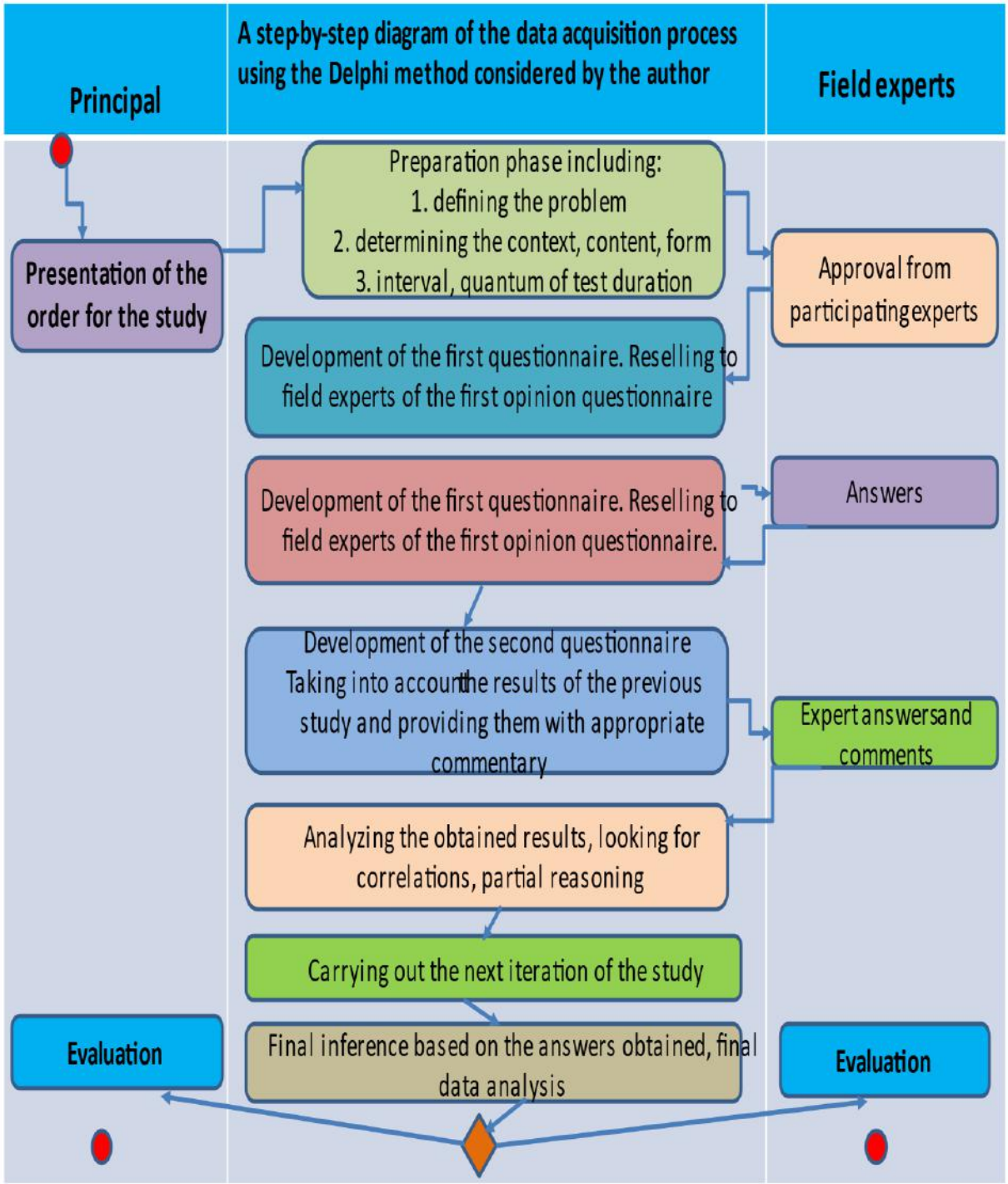


Fig. 6. The Delphy method in UML notation: *swimming lanes* and *activity diagram*
Source: own study

Table 3. Comparative matrix of systems and the degree of fulfillment of the criteria

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	8	7	6	8	8	9	7	8	7	7	8	6	8	8	8	6	4	8
Technology	9	7	4	9	5	9	6	9	8	9	7	8	9	8	9	7	9	7
Range of Functions	6	6	6	6	6	6	6	6	6	3	5	5	6	6	5	6	7	6
Integration and incorporation	4	3	5	7	3	4	8	1	5	7	4	6	5	9	4	3	4	3
Cryptography	6	3	6	9	6	8	4	2	6	2	6	3	4	6	3	6	5	6
Innovation	7	8	8	7	6	6	7	8	7	5	6	2	7	8	8	6	7	7
Security policy	5	5	7	8	6	6	6	6	9	7	5	6	6	6	9	5	6	9
Help and support	8	2	7	6	7	5	8	8	9	9	6	4	5	8	4	8	9	8

Source: own study

The data collected in this way from an independent opinion-giving group allows us to assume and assume the representativeness of both the information itself and the results of the study. However, the study does not have any tool that could validate this data. Spearman's correlation coefficient was used to determine the correctness of the assessments obtained. It is also mentioned that other metrics can be successfully used for this purpose, such as the coefficient of the level of linear dependence by Karl Pearson or the Cronbach reliability index Alpha. The Cronbach Reality Index Alpha is a statistical measure used to assess the reliability of a measurement scale. Using Cronbach's alpha, the correlation between the answers to individual questions from the interview questionnaire and the total result of the measurement is checked. The stronger the correlation, the greater the likelihood that the scale is reliable and measures the specific construct, dimension, property that is being measured. Cronbach's alpha can take a value from 0 to 1, where 0 means no correlation at all (the scale is not reliable) and 1 means "perfect" correlation (the scale is fully reliable). The correlation coefficient r, also known as the Pearson correlation *coefficient Pearson Product Moment Correlation Coefficient*) is a measure of the strength of the linear relationship between two quantitative variables and is defined as follows:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{(n-1)S_x S_y}$$

where:

S_x – sample standard deviation for variable x

S_y – sample standard deviation for variable y

The correlation coefficient is always between –1 and 1, including –1 and 1. In further considerations, Spearman's measures were used because they are characterized by low

sensitivity to input data, which is a key issue from the point of view of this work. Spearman's rank correlation coefficient was chosen because it is an excellent estimator of the value of individual ranks for the information obtained (included in the table above). Knowing the value of the rank calculated in this way, we can determine the mutual relationship between the two values. The overriding motive for using the described mechanism is the ability to ensure that the consistency and consistency of data has been ensured and maintained. Hence, the Spearman index was used . It is also worth mentioning that the obtained Spearman values are not as sensitive as, for example, those presented in the AHP strategy. The successive values of the coefficient was calculated as follows:

$$Q = 1 - \frac{6\sum d_i^2}{n^3 - n}$$

where:

d_i – difference of successive ranks in values compared in pairs;

n – number of tested features (criteria).

To estimate successive values of the correlation coefficient, the data was normalized as follows, assuming the value of parameter P equal to unity:

$$x_i = \left(\frac{x_i - \min}{\max - \min} \right)^P$$

The introduced normalization was adopted to facilitate the calculations. It is emphasized that all proportions have been preserved, because the chosen method of normalization does not change the level of system differentiation. The table 4 shows the data after normalization.

Table 4. A normalized matrix of values for the degree to which the criteria for comparing systems are met

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	0.8	0.8	0.5	0.6	1	1	0.7	0.8	0.5	0.7	1	0.6	0.8	0.67	0.8	0.6	0	0.8
Technology	1	0.8	0	1	0.4	1	0.5	1	0.7	1	0.7	1	1	0.66	1	0.8	1	0.6
Range of Functions	0.4	0.6	0.5	0	0.6	0.4	0.5	0.6	0.2	0.1	0.5	0.5	0.4	0	0.3	0.6	0.6	0.5
Integration and incorporation	0	0.1	0.2	0.3	0	0	1	0	0	0.7	0	0.6	0.2	1	0.2	0	0	0
Cryptography	0.4	0.2	0.5	1	0.6	0.8	0	0.1	0.3	0	0.5	0.2	0	0	0	0.6	0.2	0.5
Innovation	0.6	1	1	0.3	0.6	0.4	0.8	0.9	0.5	0.4	0.5	0	0.6	0.67	0.8	0.6	0.6	0.7
security policy	0.2	0.5	0.8	0.7	0.6	0.4	0.5	0.6	1	0.7	0.3	0.7	0.4	0	1	0.4	0.4	1
Help and support	0.8	0	0.8	0	0.8	0.2	1	0.9	1	1	0.5	0.3	0.2	0.67	0.2	1	1	0.8

Source: own study

With the normalized evaluation values of individual GIS systems, certain conclusions can be drawn. To illustrate them, a special type of chart was used, in which all considered features – criteria were grouped and the degree of fulfillment of a given criterion by the considered system was visually shown (Fig. 7). Further indicators (weights) have not been included in the chart due to its legibility.

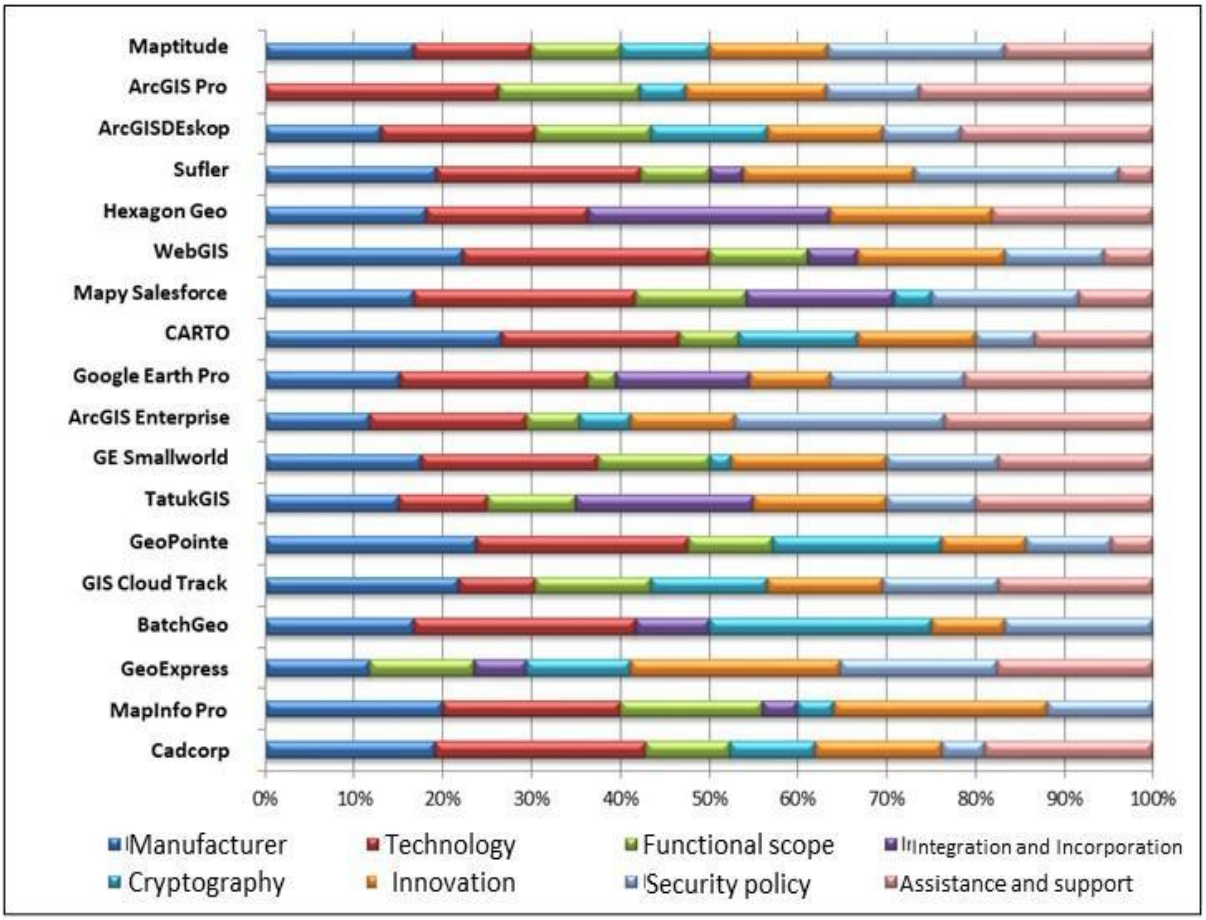


Fig. 7. The degree of fulfillment of the criteria
Source: own study

With normalized input data for the algorithm, the significance function was examined – the assessment of the implementation (fulfilment) of a given criterion by the considered business system. After creating the interval ranges for the evaluation function, they were assigned an appropriate numerical value, which was mapped to the saturation intensity of a particular cell color. When determining subsequent classes, the following classification criteria were created:

- ★ class I – min+a *0;
- ★ class II – min+a *0.52;
- ★ class III – min+a *0.69;
- ★ class IV – min+a *0.81;
- ★ class V – min+a *0.91;
- ★ class VI – min+a *1;

where:

min – the minimum known value from the input matrix that groups the expert evaluations

a – specific value (feature weight) of a given cell

In this way, a map was created showing the degree of fulfillment of individual criteria for each of the tested systems, which is presented in table 5.

Table 5. Individual assessments and significance classes presented in the form of an assessment map

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Producer	0.8	0.83	0.5	0.67	1	1	0.75	0.87	0.5	0.71	1	0.67	0.8	0.67	0.83	0.6	0	0.83
Technology	1	0.83	0	1	0.4	1	0.5	1	0.7	1	0.75	1	1	1	1	0.8	1	0.67
Range of Functions	0.4	0.67	0.5	0	0.6	0.4	0.5	0.63	0.3	0.14	0.25	0.5	0.4	0.5	0.33	0.6	0.6	0.5
Integration and incorporation	0	0.17	0.25	0.33	0	0	1	0	0	0.71	0	0.67	0.2	0.67	0.17	0	0	0
Cryptography	0.4	0.17	0.5	1	0.6	0.8	0	0.13	0.3	0	0.5	0.17	0	0.17	0	0.6	0.2	0.5
Innovation	0.6	1	1	0.33	0.6	0.4	0.75	0.88	0.5	0.43	0.5	0	0.6	0	8.83	0.6	0.6	0.67
Security policy	0.2	0.5	0.75	0.67	0.6	0.4	0.5	0.63	1	0.71	0.25	0.67	0.4	0.67	1	0.4	0.4	1
Help and support	0.8	0	0.75	0	0.8	0.2	1	0.87	1	1	0.5	0.33	0.2	0.33	0.17	1	1	0.83

Source: own study

In the conducted study, the aim is to obtain an occurrence – an instance of the system, which is the best in terms of all considered criteria, an approximation to the so-called model of an ideal system that meets all the criteria to the greatest extent possible. Therefore, the coordinates of the standard were determined based on table 4 as the maximum (best) values of the degree of fulfillment of the criteria by the tested systems. The coordinates of the pattern are presented in table 6.

Table 6. Pattern coordinates

	Producer	Technology	Range of functions	Integration and incorporation	internationalization	Customization and expansion	Policy safety	support
Template	1	1	0.667	1	1	1	1	1

Source: own study

Determining the best GIS system, i.e. the system closest to the pattern, requires defining the concept of the distance of the system from the pattern. In taxonomy, there are many measures of distance between multi-feature objects that can be used in this work. Due to the nature of the values adopted to assess the degree of fulfillment of the criteria (continuous), the Mińkowski metric with the parameter p = 2 (Euclidean distance) was used in the work to determine the distance between the tested systems and between them and the adopted model:

$$d(x_i, x_k) = d_{ik} = \sqrt{\sum_{j=1}^{m} (x_{ij} - x_{kj})^2}$$

where:

x_{ij} – the value of the object x_i in terms of the examined feature j

m – number of features.

The system (compromise solution) with the smallest Euclidean distance from the pattern will be considered the best. Table 7 gives the Euclidean distances between the tested systems and between the systems and the reference.

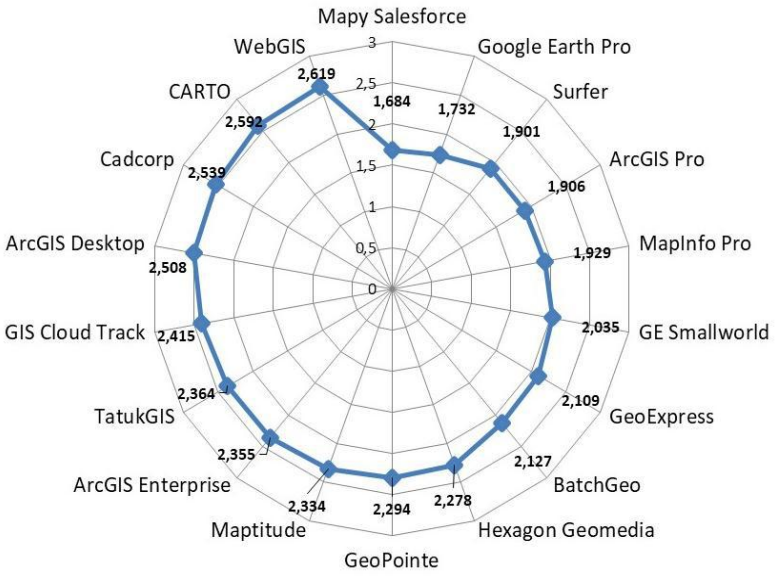
Table 7. Matrix of Euclidean distances between the tested systems and the standard

	Cadcorp	MapInfo Pro	GeoExpress	BatchGeo	GIS Cloud track	GeoPoint	TatukGIS	GE Smallworld	ArcGIS Enterprise	Google Earth Pro	CARTO	Salesforce maps	WebGIS	hexagon Geomedia	surfer	ArcGIS Desktop	Insert GT	maps
Cadcorp	0.0	1.1	1.2	1.0	0.9	0.6	0.9	0.7	1.1	1.2	0.6	1.3	0.6	0.7	1.3	0.6	0.9	1.1
MapInfo Pro	1.1	0.0	1.2	1.4	1.0	1.1	1.1	1.0	1.5	1.6	0.9	1.2	0.7	1.3	1.2	1.0	1.3	1.4
GeoExpress	1.2	1.2	0.0	1.2	0.7	1.3	0.7	1.3	1.0	1.5	1.0	1.5	1.2	1.1	1.4	0.9	1.2	0.9
BatchGeo	1.0	1.4	1.2	0.0	1.2	0.7	1.1	1.4	0.8	1.4	1.1	1.4	0.9	0.8	1.1	1.2	1.3	0.9
GIS Cloud track	0.9	1.0	0.7	1.2	0.0	0.9	0.8	1.1	1.1	1.4	0.6	1.2	0.9	1.0	1.3	0.6	1.2	0.9
GeoPoint	0.6	1.1	1.3	0.7	0.9	0.0	1.1	1.1	1.1	1.4	0.7	1.2	0.6	0.9	1.1	0.9	1.3	1.0
TatukGIS	0.9	1.1	0.7	1.1	0.8	1.1	0.0	1.1	1.0	1.1	0.8	1.2	0.9	0.6	1.3	0.8	1.0	1.1
GE Smallworld	0.7	1.0	1.3	1.4	1.1	1.1	1.1	0.0	1.1	1.2	1.0	1.4	0.7	1.2	1.1	0.9	1.0	1.1
ArcGIS Enterprise	1.1	1.5	1.0	0.8	1.1	1.1	1.0	1.1	0.0	1.2	1.2	1.4	1.0	0.9	0.9	1.1	1.0	0.4
Google Earth Pro	1.2	1.6	1.5	1.4	1.4	1.4	1.1	1.2	1.2	0.0	1.2	1.1	1.1	1.2	1.2	1.3	1.4	1.3
CARTO	0.6	0.9	1.0	1.1	0.6	0.7	0.8	1.0	1.2	1.2	0.0	1.0	0.7	0.9	1.2	0.6	1.2	1.1
Salesforce maps	1.3	1.2	1.5	1.4	1.2	1.2	1.2	1.4	1.4	1.1	1.0	0.0	1.0	1.4	1.4	1.1	1.3	1.5
WebGIS	0.6	0.7	1.2	0.9	0.9	0.6	0.9	0.7	1.0	1.1	0.7	1.0	0.0	0.8	0.8	0.9	1.0	1.0
hexagon Geomedia	0.7	1.3	1.1	0.8	1.0	0.9	0.6	1.2	0.9	1.2	0.9	1.4	0.8	0.0	1.3	1.0	1.1	1.1
surfer	1.3	1.2	1.4	1.1	1.3	1.1	1.3	1.1	0.9	1.2	1.2	1.4	0.8	1.3	0.0	1.4	1.4	0.9
ArcGIS Desktop	0.6	1.0	0.9	1.2	0.6	0.9	0.8	0.9	1.1	1.3	0.6	1.1	0.9	1.0	1.4	0.0	0.7	1.1
Insert GT	0.9	1.3	1.2	1.3	1.2	1.3	1.0	1.0	1.0	1.4	1.2	1.3	1.0	1.1	1.4	0.7	0.0	1.2
maps	1.1	1.4	0.9	0.9	0.9	1.0	1.1	1.1	0.4	1.3	1.1	1.5	1.0	1.1	0.9	1.1	1.2	0.0
Distance from the pattern	2.5	1.9	2.1	2.1	2.4	2.3	2.4	2.0	2.4	1.7	2.6	1.7	2.6	2.3	1.9	2.5	1.9	2.3

Source: own study

Based on the above relationships, a pattern was established, which is a reference point for each system under consideration for each system under examination. This pattern is equivalent to an ideal system. Below, in the tabular layout, in the last line, the model value of the significance function is presented, which is performed by each of the examined systems. Of course, the model value depends on the experts' assessments, and in this case its components are created by the maximum number (the highest rating) of features among the subsequent considered GIS systems. The final step of the undertaken network of actions is to determine the exact distance that separates each of the tested GIS class systems from the established ideal point. Referring to the pattern coordinates shown above (table 8), the following results were obtained (sorted in ascending order from the ideal point).

Table 8. Distance of individual systems from the pattern

Salesforce maps	**1.684**	
Google Earth Pro	1.732	
surfer	1.901	
ArcGIS Pro	1.906	
MapInfo Pro	1.929	
GE Smallworld	2.035	
GeoExpress	2.109	
BatchGeo	2.127	
hexagon Geomedia	2.278	
GeoPoint	2.294	
maps	2.334	
ArcGIS Enterprise	2.355	
TatukGIS	2.364	
GIS Cloud track	2.415	
ArcGIS Desktop	2,508	
Cadcorp	2,539	
CARTO	2,592	Dirichlet tessellation of the results of ranking a set of GIS systems according to multi-criteria Pareto optimization
WebGIS	2.619	

Source: own study

As mentioned, the table 8 presents the distance of the tested systems from the reference solution. *Rank In Cathegory* (RIC) values are presented in the form of Dirichlet tessellation, which represent the distances of the systems from the pattern. The attached Voronoi diagram shows directly that all considered systems are within (orbit) the ideal point due to slight differences in distances. However, only some of them can be regarded as Pareto optimal choices. Analyzing the obtained results, the Pareto optimal system in relation to the considered set of criteria is the QuickStep product. It is repeatedly emphasized that the considerations conducted here include a comprehensive set of criteria, so the selected GIS system is the best in terms of all considered features. This is a very important property of multi-criteria optimization. The obtained ranking results also highlight another fact, which shows to what extent the considered systems are like each other. The difference between the first two features (the winning Salesforce Maps

and second in the Google Earth Pro ranking) is only 0.047127121. Similarly, there are slight deviations from the next values obtained in the ranking, between successive pairs of the tested systems.

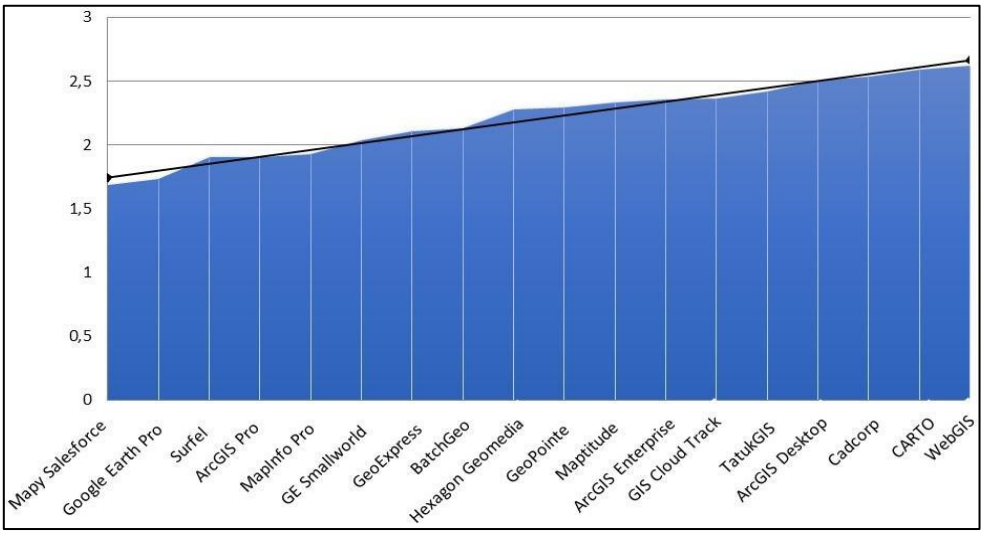


Fig. 8. An area chart with a trend obtained in a multi-criteria analysis of Pareto optimization
Source: own study

The above-mentioned dependence was illustrated by means of a layer diagram, showing the value of the function of the distance of a specific object (system) from the pattern (Fig. 8). There is an almost linear upward trend (placed on the chart), but it is not rapid. The distance closest to the pattern (in relation to the currently used multi-criteria optimization method) is represented by Salesforce Maps and Google Earth Pro, while the farthest are WebGIS and CARTO. Concluding the conducted research, it was found that the applied multi-criteria optimization method is perfectly applicable in the considered problem of selecting the best solution. It implies the creation of a ranking of objects and their alternatives in a properly established order.

Conclusion

The aim of the research was to conduct a multi-criteria comparative analysis of integrated GIS-class IT systems for small and medium-sized enterprises (SME). The main reason for using Pareto multi-criteria optimization (also in this work) is to model the collective (group) preferences studied in the work and to support the decision maker in making strategic decisions for the company. Of course, it should be borne in mind that a single solution (solution) will never be optimal for all considered criteria, which are quality indicators. Hence, the algorithms of this class make it possible to choose from among all features or criteria, the solution allocated closest (or located – in the immediate vicinity) to the Pareto optimal point (also called the ideal point). Since a large group of criteria was used in the work, deciding with so many factors often boil down to searching for a compromise solution against the background of contrasting, colliding criteria. Referring to the problem under consideration, to find such an ERP

system (a compromise solution) that would be acceptable for each decision criterion, to make a Pareto optimal decision, multi-criteria optimization should be obligatory.

Eighteen selected GIS class systems that meet the criterion of completeness of all data required in the conducted research were fully analyzed. The proper comparative characteristics were preceded by the recognition of the market situation in terms of the availability of GIS class systems in global realities. At the data acquisition stage, extensive research was carried out on commercial and free GIS solutions designed for the small and medium-sized enterprise sector.

During the implementation of the research, many difficulties were encountered that directly result from the encapsulation of companies. Currently, most organizations provide only cursory, cursory data, which they publish in the form of advertising materials and folders. In most attempts, obtaining any materials describing even basic functionalities turned out to be a very difficult task and bordered on a miracle. Certainly, this is partly due to the current shape of the law, which makes it difficult to provide and disclose information on given products, both to producers, distributors and implementers. The aspect of competition and rivalry on the market, between competing manufacturers, is also significant.

When assessing individual GIS class systems, an innovative approach was used, in which the price criterion was excluded from the analysis. The previously conducted diagnosis shows that in the vast majority it is one of the most important determinants of the evaluation of a given object, while as a reminiscence, it is worth bearing in mind that this factor is very often given by manufacturers in an imprecise way. Often, the price being a dumping or temporary – promotional price is not disclosed as the final value. In addition, it is strictly dependent on fluctuations, market moves, the frequency of introducing new versions of the system or other factors that are de facto independent of the level of advancement of the product itself.

Since the cost factor is strongly correlated with other features and criteria included in the work, the other criteria included successfully cover the cost factor. On the other hand, the contributions, functionalities and properties of the systems presented in the work, in terms of other features, are objectively measurable, constant and unchanging.

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