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COMPARATIVE CHARACTERISTICS OF GIS USING THE AHP METHOD

Abstract: The article discusses the methodology of comparative analysis of GIS class computer systems using the AHP method. Eighteen selected GIS systems that meet the criterion of completeness of all data required in the research were fully analysed. The proper comparative features were preceded by the recognition of the market situation in terms of the availability of GIS systems. Eight thematic groups of criteria were used in the research, on the basis of which GIS solutions were selected for comparison. The adopted system selection criteria carry out the selection of objects in a binary manner. The set of features and comparative criteria was created on the basis of our own experience and numerous consultations with specialists and field experts. The selected criteria are the most commonly used and most commonly accepted in the environments that systems of this class use on a daily basis. Both the functional scope (features, functions, properties, advantages and disadvantages) and the degree of fulfillment of subsequent criteria by the considered systems were defined and described.

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Introduction

In the information society we are approaching, information and knowledge play an essential role. Despite the fact that they are intangible, they generate added value. Therefore, in times of such rapid development of knowledge and the related ubiquitous expansion of information, resulting in economic growth, GIS class systems were created on the basis of technology and business solutions, oriented on the use of information for comprehensive management of various types of entities, such as: economic organizations, companies, enterprises, systems, etc. GIS systems find practical application in many fields. Hence the diversity of terms for geographic information processing systems, such as geographic database information system, geographic data system, and spatial information system. Each of these terms approximates in some way the functions performed by individual systems. In practice, the most common are specialized systems, focused on a narrow group of applications, however, there are also multi-purpose general-purpose GIS.

The purpose of this article is to present a hierarchical comparative analysis of GIS enabling the selection of a properly tailored and effective GIS solution for a given enterprise, using the AHP (Analytic Hierarchy Process) method. The results obtained using this method 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 it.

This article consists of six sections. The first section covers assumptions and key concepts. The second section contains the results of the literature review, on the basis of which GIS classes and categories 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. The implementation of the topic was based on the possibly available bibliography specified in the chapters: "Assumptions and basic concepts" and "Overview of the studied GIS systems". In addition, numerous industry magazines of general circulation were used, concerning IT, outsourcing, design, problem and utility solutions related to GIS systems. Numerous consultations and meetings, e-mails and expert opinions from employees and experts from companies that produce and implement GIS class systems were also an invaluable source of data.

Assumptions and basic concepts

The concept of GIS and classification. GIS are the result of the revolution in geography taking place over the last dozen or so years, as well as, of course, the rapid development of information technology and database management methods (data collections). The creation of GIS is the result of a combination of works carried out in various fields: geography, cartography, geodesy, computer science, electronics. Geographic information system technology uses geographic concepts, applications and computer systems. A geographic information system is a tool that analyzes spatial relationships, patterns, and trends. This can be achieved by combining geography with

available data, making GIS more understandable in a geographic context. GIS includes both hardware and software systems. The geographic information system consists of several groups of programs (modules) performing separate functions. These are:
- procedures for entering and verifying input data,
- procedures for managing and processing within the database (database management system),
- procedures for processing and analyzing geographical data,
- output procedures: graphical, cartographic and textual presentation of data,
- user communication procedures.

GIS find practical application in many fields. Hence the diversity of terms describing systems that process geographic information, such as geographic database information system, geographic data system, spatial information system. Each of these terms approximates in some way the functions performed by individual systems. In practice, the most common are specialized systems, focused on a narrow group of applications, however, there are also multi-purpose general-purpose GIS. A wide group of GIS applications is presented in figure 1.

Fig. 1. GIS application areas
Source: https://www.educba.com/applications-of-gis/

The main areas of a GIS are creating geographic data, managing that data in a database, analyzing patterns to create, and visualizing it on a map. GIS provides a better understanding of spatial patterns and relationships. Thus, GIS technology combines database operations such as querying and statistical analysis with the unique visualization and geographic analysis offered by maps. GIS class systems or applications can be divided into the following types/models:
1. Four-dimensional GIS.
2. Multimedia or hypermedia GIS.
3. Internet GIS.
4. GIS Virtual Reality.

The characteristics of the above types of GIS are presented in table 1.

Table 1. Characteristics of GIS models

Type/Model	Characteristic [pos. literature]
Four-dimensional GIS:	It is designed to handle three dimensions of space and one dimension of time. Space-time representations can only support two dimensions of space and one dimension of time. (Bielecka, 2006; Chang and Kang-tsung, 2016; Fu & Sun, 2010; DeMers, 2009; Gaździcki, 2003; www.esri.com; Gotlib et al., 2008; Iwańczuk, 2016; www.mjcetce409.blogspot.com; Myrda & Litwin, 2005; www.wiki.osgeo.org; Szczepanek, 2017; Werner, 2004)
Multimedia /hypermedia GIS:	It allows the user to access a range of georeferenced multimedia data by selecting assets from a georeferenced image map database. A map that serves as the main index of multimedia data in a multimedia geographic representation is called a hypermap. Multimedia and virtual geographic representations can be stored in extended relational databases, object-oriented databases, or application-specific data stores. (Gaździcki, 2003; Iwańczak, 2016; www.pl.wikipedia.org; www.wseiz.pl; www.mjcetce409.blogspot.com; www.wiki.osgeo.org; Bolstad, 2019; Werner, 2004; Xuan & Zhu; 2016)
Web GIS:	Widespread access to the Internet combined with the use of web browsers and the explosion of geographic information enabled the development of new forms of multimedia geographic representations on the web. Many geomatic web solutions are web-based and are rapidly overtaking desktop GIS, and future trends are moving in the same direction. (Bielecka, 2005; Goodchild, 2010; www.pl.wikipedia.org; www.wseiz.pl; www.mjcetce409.blogspot.com; www.geoforum.pl; www.en.wikipedia.org; Bolstad, 2019; Szczepanek, 2017; Werner, 2004; Xuan & Zhu; 2016)
Virtual Reality GIS:	Virtual Reality GIS was developed to enable the creation, manipulation and exploration of geo-referenced virtual environments. For example, using Virtual Reality Markup Language (VRML) to experiment with different scenarios. GIS virtual reality can also be web-based. An example of the use of Virtual Reality GIS is a 3D simulation for planning in various scenarios. (Iwańczak, 2016; www.mjcetce409.blogspot.com; www.wiki.osgeo.org)

Source: own elaboration

Assumptions. Due to the large number of GIS systems on the market, it is impossible to obtain information about all products. The main difficulties were related

to the acquisition of the necessary materials. 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 size of the considered set of studies consists of GIS systems selected from all available on the world market today,
- the selection of systems for comparison was based on the binary technique, in which the presence of any information in the aspect of eight thematic groups of criteria was detected,
- the vast majority of the GIS systems presented in the work are commercial products, although the earlier, preliminary environmental analysis also included "open source" systems,
- but to be a true GIS, the system must contain a significant group of components (Fig. 2).
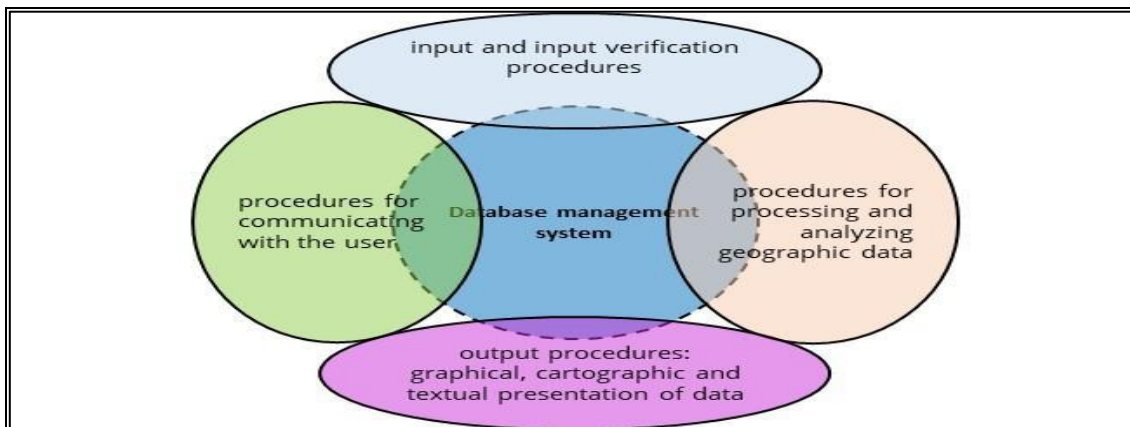

Fig. 2. Basic components of the GIS system
Source: own elaboration

Analytic Hierarchical Process (AHP). A methodology called AHP was used to prepare the proper ranking of the examined GIS class systems. The research was based, among others, on this strategy due to the fact that AHP, by representing the decision problem in a strictly hierarchical manner, ensures obtaining a more accurate, more representative solution, through the step by step technique of successive *actions*. Analytic Hierarchy Process ensures finding the optimal solution in a multi-criteria decision problem. AHP effectively supports the decision-maker in the decision-making process. This methodology allows for a hierarchical decomposition of the problem issue into individual, smaller units – actions to be considered. It can operate on archival or long-term data. The operating logic of AHP has the ability to detect inconsistencies contained in operational data. The AHP strategy allows for a convenient compilation of data, and thanks to the mechanism of mutual comparison of individual criteria in pairs, through association – assigning weight to a given feature, prioritization is established, and thus the level of significance of a given criterion is determined. The method used in the work reduces bias in making the right decision, and in its interpretation of the result AHP takes into account both subjective and objective assessments of experts. Thanks to

this, the obtained result is representative and consistent with the real state. In the considered problem of choosing the right GIS system, the AHP algorithm finds an ideal application. The idea of the algorithm ensures that a compromise is reached and a common consensus is reached thanks to the synthesis of all criteria and partial results. The AHP method seems to be the best method due to the possibility of obtaining a representative and factual result, taking into account both subjective and objective assessments of experts. In addition, this method detects inconsistencies in operational data and reduces bias in decision-making (Mu & Pereyra-Rojas, 2017; Saaty, 2012).

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).
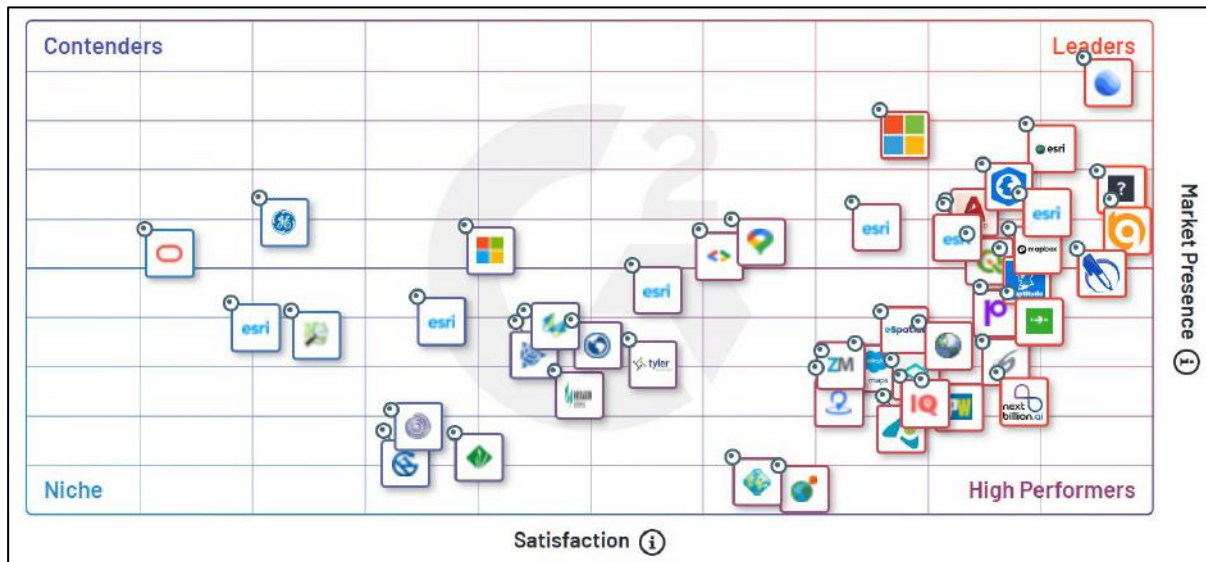

Fig. 3. GIS class solutions for enterprises
Source: own elaboration

Bearing in mind the limitations concerning the volume of the article, only six systems will be characterized in this subchapter: TatukGIS, Cadcorp, CARTO, Map Salesforce, GeoExpress, Geopointe. Other GIS can be found in studies (Miłek et al., 2023a; Miłek et al., 2023b).

TatukGIS is a professional all-in-one GIS mapping and data editing application with a built-in scripting environment for customization and feature extensions. TatukGIS is not just a simple tool to open and view GIS and CAD files. Its advanced feature set makes it a winner in its category, providing a comprehensive tool for rendering high-quality maps and working with GIS data. The program is equipped with typical GIS features and provides an extensive feature set, allowing you to include

multiple vector file formats in one project, organize, group and prioritize layers, customize layer properties, legend and map appearance by changing colors and styles, adding labels and adjusting transparency. Official screenshots:
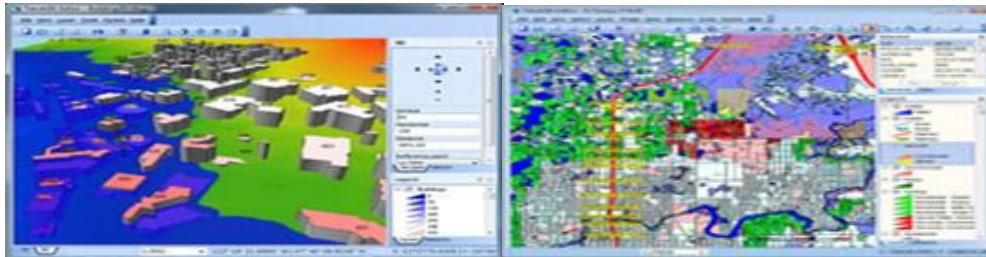
Basic functions:

The program is equipped with typical GIS functions. Functional range incl. includes:
- Zoom in, zoom out, pan maps.
- Multiple vector file formats (layer types) in the same project.
- Extended legend for hierarchical layers, layer grouping, subprojects.
- MiniMap window with options for the World Map or Continent Map tabs.
- TatukGIS project files.

Advantages:
- The editor has a very high level of flexibility in handling data.
- Loading, editing, exporting, importing – all basic GIS functions available.
- A very long list of supported formats in raster and vector data.
- Supported różnedatabase formats and finally supported web services.
- TatukGIS DK API.
- The application speed is great and has left many GIS applications behind.
- The Script Editor can be used in conjunction with other GIS applications on the market.

Disadvantages:
- Some parts of the GUI should be updated to use other GIS solutions.
- You would need to write a number of import routines and a number of data enrichment tools using the built-in script editor.

Cadcorp – is an integrated family of geospatial products that includes desktop, web and software products. It has been designed with the needs of both end users and application developers in mind, to be used in all phases of spatial data management – from development, through application development, deployment and data distribution. Cadcorp offers an integrated family of geospatial software that includes desktops, servers, websites, and software products. Cadcorp provides a wide range of map and data services that feature content from a variety of providers, including Ordnance Survey. Official Screenshots:

Basic functions:

Cadcorp integrates both GIS and CAD into one application. It almost flawlessly adds rich functionality to mapping and styling. It adds several features, ribbon interface, interoperability and development tools. But when you combine it with server and cloud tools, the lesser-known Cadcorp shines on several levels. Range functional:

- Cropping, color balance, remapping and more.
- Combining multiple images into seamless mosaic datasets.
- Creation custom images.
- Create MrSID files using existing images and GIS data.
- Export only the selected fragments of photos, exactly in the required size and resolution.

Advantages:

- Intuitive interface for Desktop GIS.
- Creating Cadcorp SIS web maps.
- Hosting and sharing data in the cloud.
- Deloy web applications via server.
- Development tools available for customization.

Disadvantages:

- Lack community forum support.
- A small collection of tools remote sensing.
- A new product without much background information.
- CAD/GIS specialist, but lacks other fields.

CARTO is the leading Location Intelligence platform. It enables organizations to use spatial data and analytics for more efficient delivery routes, better behavioral marketing, strategic store placement, and much more. Data Scientists, Developers and Analysts use CARTO to optimize business processes and predict future results with the power of Spatial Data Science. CARTO is the user interface for our next-generation cloud-native Location Intelligence platform. CARTO is available for both individuals and enterprises, both in cloud and self-hosted deployments. Depending on how you use the CARTO platform, whether for visualization, analysis, data access or application development, you will use different platform components. Official screenshots:
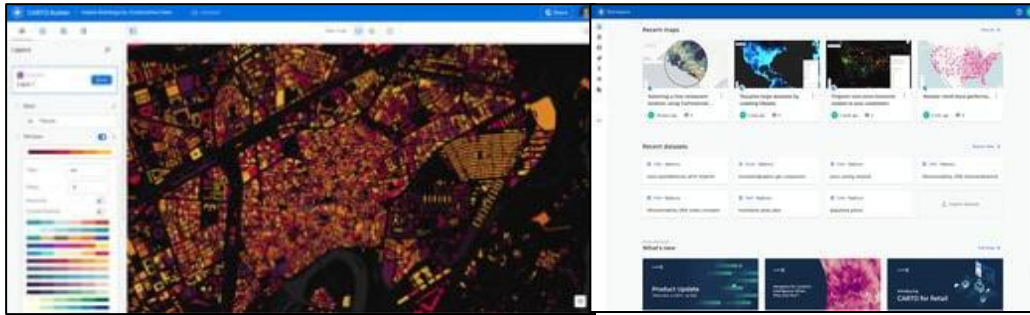
Basic functions:

It allows you to create stunning maps and perform large-scale spatial analysis, all running directly on cloud data warehouses. The platform helps you visualize, analyze and build apps using location data natively on cloud data warehouse platforms.

Cartography:
- Design.
- Mapping vector.
- Visualization data.
- Overlaying.

Analysis:
- Analysis predictive.
- Analysis distances.
- Analysis spatial.
- Stream data.

Reporting:
- Transformation data.
- WYSIWYG design.
- Integrations.

Advantages:
- Flexibility APIs.
- An easy-to-use way to manipulate geospatial data.
- A huge variety of tools, from a friendly user interface (builder), to a python library (cartoframes), as well as an SDK and API pool.
- Extensive documentation and fast response of the CARTO support team.

Disadvantages:
- There are discrepancies in how billing is done and a gap between billing and those who deal with marketing and negotiating.
- Guidelines for embedding, creating and modifying maps could be easier for users.
- Data integration and scheduled refresh need to be more user friendly.

The leading location analysis tool for Salesforce | Leverage mapping and optimization technologies to maximize the productivity of your sales and service assets. Salesforce is your customer success platform, designed to help you sell, service, market, analyze, and connect with your customers. Run your

business from anywhere with Salesforce. Use standard products and features to manage relationships with prospects and customers, collaborate and engage with employees and partners, and store your data securely in the cloud. But standard products and features are only the beginning. With our platform, you can customize and personalize the experience for your customers, partners, and employees and easily extend beyond out of the box functionality. Official screenshots:
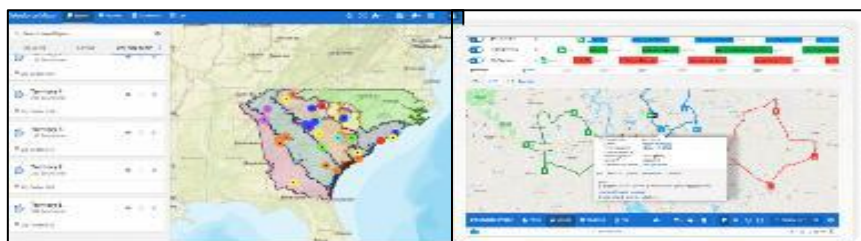
Basic functions:

The program is equipped with typical GIS functions. Functional range incl. includes:
- Sales automation.
- Contact and account management.
- Task / activity management.
- Territory and quota management.
- Management of products and price lists.
- Management of offers and orders.
- Customer contract management.
- Marketing automation.
- Campaign management.
- Lead management.
- Customer service.
- Case management.
- Reporting and analytics.
- Reporting.
- Forecasting.

Advantages:
- Provides a clear line of communication between the parties and creates a solid reporting structure.
- Very satisfying and easily accessible.

Defects:
- Interfejs unfriendly to use.
- Flows and more complex business process workflows continue to be a technical challenge.
- Administrator management can be complicated, hard to find what you need when setting up an instance.

GeoExpress – A powerful tool for compressing and adjusting images and GIS data. GeoExpress provides a comprehensive set of editing tools to create the exact image you need GeoExpress enables geospatial specialists to compress images into our proprietary, industry standard MrSID format. This format supports lossless and visually lossless compression, allowing users to reduce file sizes without sacrificing image quality. Using GeoExpress and Express Server reduces our storage costs and allows us to manage images in a central location, which in turn reduces redundancy and increases our efficiency. Official screenshots:
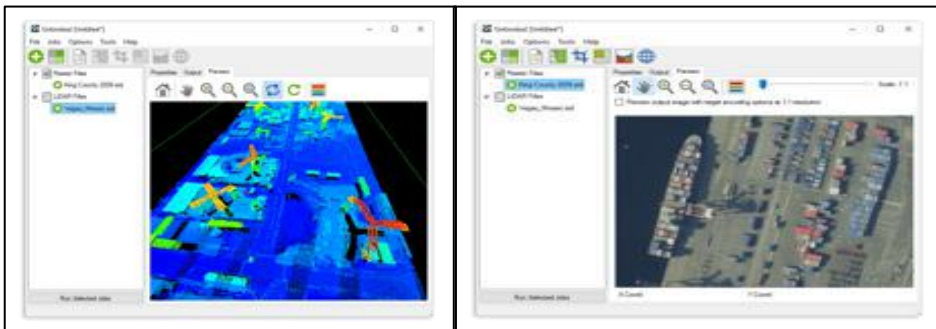
Basic functions:

The program is equipped with typical GIS functions. GeoExpress also provides editing capabilities to compress geospatial photos so you can provide enhanced visual data for analysis. It includes standard photo editing features such as cropping and color balancing, as well as re-display, mosaic and more. Functional range incl. includes:

- Spatial analysis.
- Data acquisition.
- Data visualization.
- Data storage.
- Cropping, color balance, remapping and more.
- Combining multiple images into seamless mosaic datasets.

Advantages:

- COMPRESSION! No other software compresses and displays like this product.
- Images are easy to crop and reduce to a smaller target area.

Defects:

- You must purchase a container to convert to MrSID compression.
- Difficult to manage large aerial photos and image data.

Geopointe was launched in 2010 and is based in the city of Irvine, California with a presence in the United States. Geopointe is a Salesforce partner AppExchange and the leading geolocation application available on AppExchange. Geopointe is a great mapping tool that is constantly updated to meet customer needs. Geopointe provides end users, managers, administrators and developers with multiple

ways to leverage the geographic aspects of their data to improve efficiency and streamline processes. Official drops screen:

Basic functions:

At work:
- Location.
- Communication with employees.
- Behavior monitoring.
- Reports.
- CRM integrations.

Analysis:
- Distance Analysis.
- Spatial Analysis.

Cartography:
- Map design.
- Data visualization.
- Overlaying.

Reporting: Data transformation.

Advantages:
- A great mapping tool that is constantly updated to meet customer needs.
- Integrates well with Google Maps.
- Powerful mapping ability – visualize any geographic information in Salesforce.
- Seamless integration with Salesforce – ready functionality for geocoding addresses from Salesforce fields.
- Ease of use – very low to minimal learning curve. It is very user friendly and intuitive.
- Continuous implementation of new features and improvements.

Defects:
- Filtering and creating a dataset may seem too complicated at first.
- Sometimes the map doesn't like to load all amenities.
- no mechanisms to export the Geopointe list directly to reports or Salesloft.
- The scrolling feature on the map is a bit tricky to use.

Methodology

A methodology called AHP was used to prepare the proper ranking of the examined GIS class systems. This methodology allows for a hierarchical decomposition of the problem issue into individual, smaller units – actions to be considered. The AHP strategy allows for a convenient compilation of data, and thanks to the use of the mutual pairwise comparison mechanism, *pairwise comparison*) of individual criteria, through association - assigning a weight to a given feature, prioritization is established, and thus the level of significance of a given criterion is determined. The method used in the work reduces bias in making the right decision, and in its interpretation of the result AHP takes into account both subjective and objective assessments of experts. Thanks to this, the obtained result is representative and consistent with the real state. AHP consists of three main steps: constructing a hierarchy, creating a pair comparison matrix, and calculating the importance of individual criteria . The complex idea of the algorithm is presented in the following diagram (Fig. 4) in the three-step form (synergy of three components):
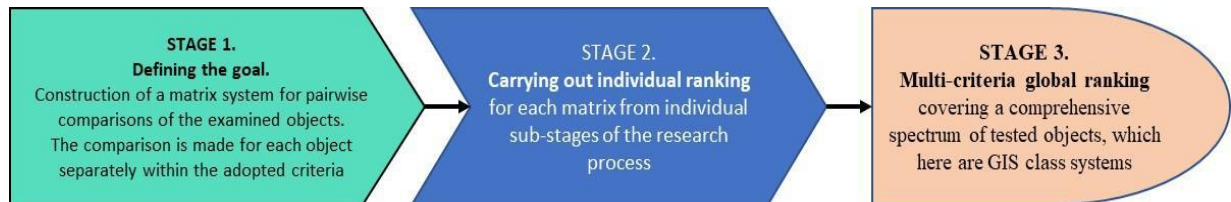
Fig. 4. A step-by-step approach to the AHP algorithm when evaluating GIS systems
Source: own elaboration

Step 1: Hierarchy construction. The first step in the AHP method is to build a decision hierarchy where all the factors that influence the decision are broken down into levels of the hierarchy, starting at the highest level and then going down in the hierarchy. The top level of the hierarchy usually represents the goal or main goal to be achieved, and the lower levels represent criteria or alternatives that are related to achieving the goal (Mu & Pereyra-Rojas, 2017). The general structure of the hierarchy is shown in the figure below (Fig. 5).
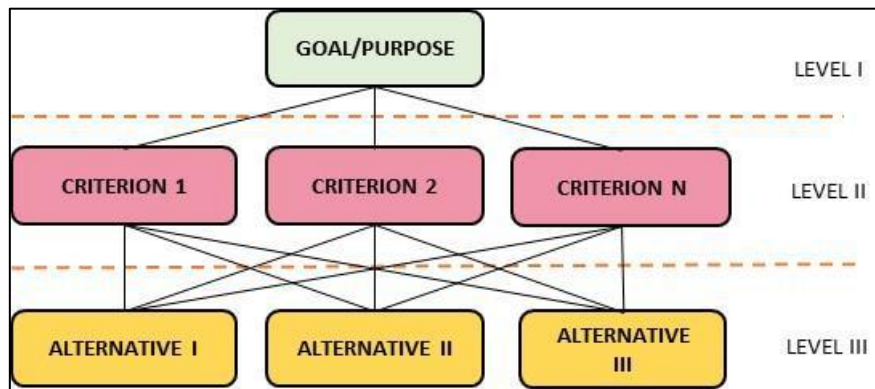
Fig. 5. Scheme of the structure of the hierarchical model
Source: own elaboration

The first level of the hierarchy is the goal, which is the general decision problem that needs to be solved. At this level, the goal and general category of the problem to be solved by the AHP method should be defined. The second level is the criteria, i.e. the factors that must be taken into account in the decision-making process. At this level, all criteria that are relevant to solving the problem should be specified. These criteria can be assessed on the basis of qualitative and quantitative information. The third level is alternatives, i.e. possible solutions to the problem. At this level, alternative solutions to the problem must be identified, which will be evaluated against criteria from the second level of the hierarchy. Then, at each level of the hierarchy, benchmarking should be done to determine the relative importance of each item to other items in the same category. Comparison of items can be done on a pair or group level. In this way, the construction of the hierarchy in the AHP method makes it possible to determine the hierarchical structure of the problem, which allows for a thorough and systematic comparison of different alternatives to solve the problem, as well as the evaluation of each of them on the basis of specific criteria.

Step 2: Create pair comparison matrix. A Pairwise Comparison Matrix (MPP) is then created where each criterion is compared to every other criterion in the hierarchy to determine their relative importance (Bielecka, 2006). The MPP ranges from 1 to 9, where 1 means that two criteria are equally important and 9 means that one criterion is more important than the other. Values between 1 and 9 represent the importance of one criterion relative to the other. The weighted average of the column in the MPP is then computed to give a vector of weights for each criterion. To create a comparison matrix, the Saaty scale is used, which is presented in the table 2 (Saaty, 2012).

Table 2. Scale of comparisons used in the AHP method

Importance scale	Definition	Explanation
1	Equal importance	Both elements have an equal impact on achieving the goal, or when it is difficult to determine which of them is more important for achieving the goal.
3	Weak or moderate advantage	Slight (moderate) distinction or slight preference for one element over another.
5	Strong advantage	A clear distinction or significant favoritism of one element over another.
7	A very strong advantage	Predominance or clear preference for one element over another.
9	Extreme or absolute advantage	Extremely clear advantage of one element over the other, which reaches the maximum level possible to estimate.
2, 4, 6, 8	Intermediate values are used only when necessary	In some cases, it is necessary to numerically interpolate compromise opinions because there are no adequate words to describe them (intermediate values from the above scale are used in such situations).

Source: own elaboration

Based on the above scale, the decision maker issues scores for individual criteria, which are then placed in a square matrix. When making pairwise comparisons, a rule should be followed that the rating value for the less important or less preferred item is the reciprocal of the rating value for the more important or more preferred item, as determined by the decision maker. If one element is more important than the other, it receives a higher score, e.g. 3, 5 or 9, depending on the degree of superiority over the other element. On the other hand, less important or less preferred elements in the compared pairs receive lower rating values, e.g. 1/3, 1/5 or 1/9. When the decision maker considers that two items are equivalent, they are given a score of 1. The table 3 shows an example pairwise comparison matrix.

Table 3. Matrix of comparisons

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E
Criterion A	1	5	1/2	1/2	3
Criterion B	1/5	1	1/3	1/5	1
Criterion C	2	3	1	2	2
Criterion D	2	5	1/2	1	3
Criterion E	1/3	1	1/2	1/3	1
Sum	5.53	15	2.83	4.03	10

Source: own elaboration

The next step in this step is to normalize the matrix shown above to the next matrix by dividing each element of a given column by its sum. The weights were calculated using the arithmetic mean of the row data. The result of this operation is presented in table 4.

Table 4. Normalized matrix of comparisons

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	Scales
Criterion A	0.18	0.33	0.18	0.12	0.3	0.222
Criterion B	0.04	0.07	0.12	0.05	0.1	0.076
Criterion C	0.36	0.2	0.35	0.5	0.2	0.322
Criterion D	0.36	0.33	0.18	0.25	0.3	0.284
Criterion E	0.06	0.07	0.18	0.08	0.1	0.098

Source: own elaboration

Step 3: Calculate the importance of individual criteria. In this step, the preference matrix is built and its coherence index is calculated, which means that the global coherence of the matrix at each level of the hierarchy is examined (Mu & Pereyra-Rojas, 2017; Saaty, 2012). This is to check how consistent the information provided by the decision maker is when creating the comparison matrix. It is built on the principle that element A is equivalent to itself, while the value assigned to element B in relation to element A is the reciprocal of the value assigned to element A in relation to element B. Part of this step is also to examine the coefficients of coherence of the resulting matrix, determined by: Consistency Index (CI) and Consistency Ratio (CR). These coefficients are described by the formulas:

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

$$CR = \frac{CI}{RI} \tag{2}$$

where:

λ_{max}– the largest eigenvalue of the matrix

n– matrix size

RI– randomness index (constant value from the Random table Consistence Index, developed for this method)

The weights for table 5 are calculated on the basis of the arithmetic mean of the rows of the matrix.

Table 5. Matrix of preferences

	Criterion A	Criterion B	Criterion C	Criterion D	Criterion E	The weights of the sum of the values
Criterion A	1*0.222=0.222	1.11	0.111	0.111	0.666	0.444
Criterion B	1/5*0.076=0.0152	0.076	0.025	0.0152	0.076	0.041
Criterion C	2*0.322=0.644	1.61	0.161	0.322	0.966	0.745
Criterion D	2*0.284=0.568	1.42	0.142	0.284	1.42	0.767
Criterion E	1/3*0.098=0.0327	0.098	0.049	0.0327	0.098	0.062

Source: own elaboration

Then, the weights of the criteria (Weights of the sum of values) for table 5 are divided by the weights of the criteria (Weights) for table 4. The highest value of the own matrix is calculated on the basis of the arithmetic mean of the results obtained by dividing the weight of the sum of values (Table 6) by the weights of the criteria (Table 5) and amounts to:

$$\lambda_{max} = \frac{2 + 0{,}539 + 2{,}314 + 2{,}701 + 0{,}633}{5} = 1{,}6374$$

The index of the random discrepancy index is presented in (Table 6), which contains the average weights of the coherence indexes of random pairwise comparisons.

Table 6. Compliance index acc. Saaty

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Source: own elaboration

Results and discussion

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. It is also mentioned that the scope of the criteria has been limited by excluding the cost factor from such a large group of criteria. A full domain reconnaissance was made, covering both commercial systems and free, open source solutions. After proper data acquisition, it was decided to select objects from commercial GIS systems. The final set of systems intended for analysis included the following items: ArcGIS Pro, WebGIS, BatchGeo, Google Earth Pro, Maptitude, ArcGIS Desktop, Hexagon Geomedia, MapInfo Pro, Surfer, GIS Cloud Track, ArcGIS Enterprise, GE Smallworld, TatukGIS, Cadcorp, CARTO, Salesforce Maps, GeoExpress, GeoPointe.

Stage 1. Construction of the hierarchy. The general structure of the hierarchy is shown in the figure 6.
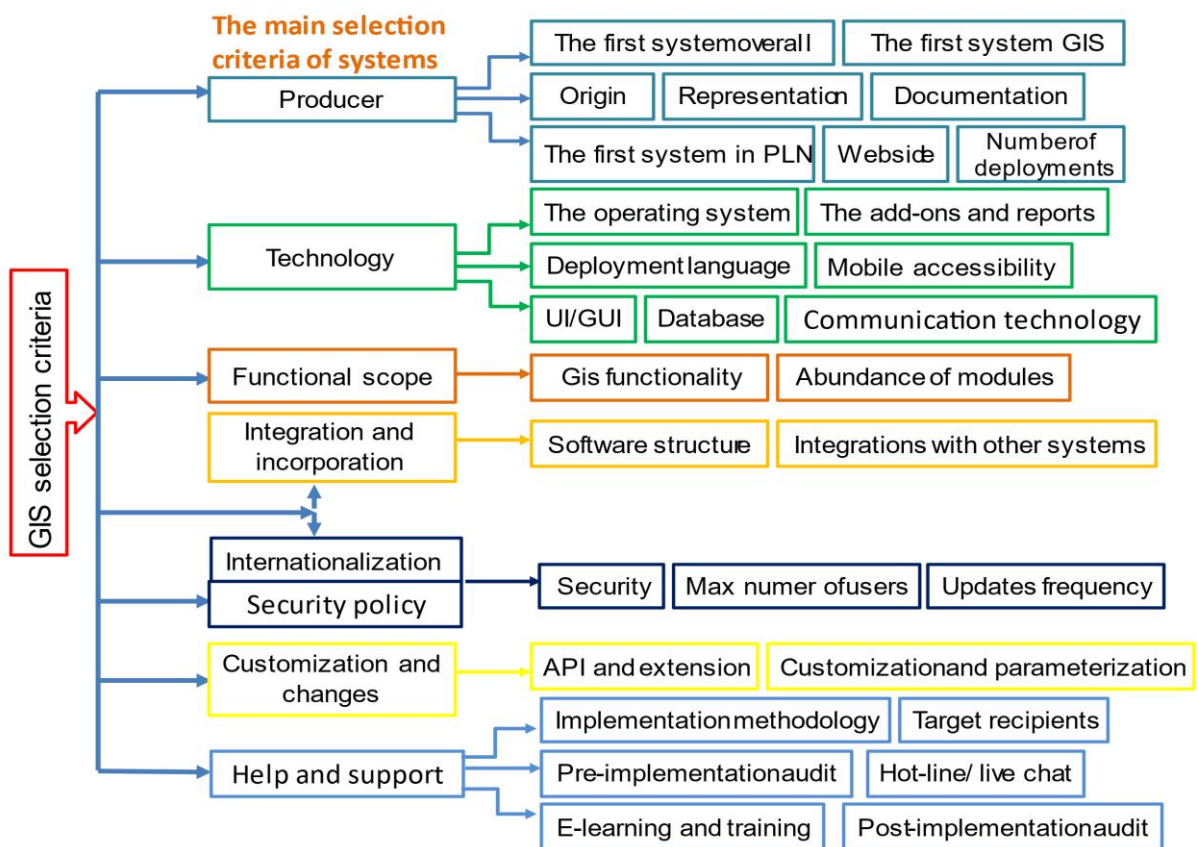
Fig. 6. Hierarchical tree structure of the GIS system selection problem
Source: own elaboration

The ordering of criteria is aimed at appropriate numbering (indexing) of feature functions and their arrangement – configuration in the appropriate order at specific levels of the hierarchy of significance. In order to achieve this goal, a nine-point adjective scale of the algorithm was used in the construction of the matrix for the assessments of

decision-makers and experts. Numerical values of consecutive comparisons (*pairwise comparise*) denote the significance function of a given assessment and, according to the idea of the algorithm, they should be included on a discrete scale, from 1 to 9. The translation of individual verbal assessments of criteria (provided by experts) into specific weight values is presented in table 7.

The weight criteria of the significance function defined in this way were used in the next step, where the decision maker (*decision maker*) or a domain expert determines the significance level of criterion A in relation to criterion B. Next, the next pairs of criteria taken from the feature matrix are scored. The study must be carried out very meticulously and precisely, due to the representativeness of the results obtained later. It is, among others, due to homogeneity – homogeneity (and thus convergence in relation to common features) in the acquisition of comparison values, the previously presented Delphi method was used. The basic matrix for the algorithm is presented in table 8.

Table 7. Translating the qualitative verbal assessments
into the weights of the AHP algorithm criteria

Qualitative verbal assessment	Translating into rank, numerical evaluation
Equally recommended/preferred {equal importance}	1
From equally to slightly recommended/preferred	2
Slightly recommended/preferred {moderately preferred}	3
From slightly to strongly recommended/preferred	4
Strongly recommended/preferred {Strongly preferred}	5
From strongly to very strongly recommended/preferred	6
Very strongly recommended/preferred {Very strongly preferred}	7
From very strongly to extremely recommended/preferred	8

Source: own elaboration

Table 8. Matrix of comparisons of the level of significance
of individual criteria in the AHP method

	Producer	Technology	functional range	Integration and incorporation	internationalization	Customization and expansion	security policy	Help and support
Producer		2.0	7.0	4.0	2.0	6.0	5.0	4.0
Technology			8.0	5.0	1.0	5.0	6.0	6.0
functional scope				4.0	9.0	2.0	2.0	3.0
Integration and incorporation					3.0	5.0	3.0	5.0
internationalization						7.0	6.0	6.0
Customization and expansion							3.0	3.0

Source: own elaboration

Based on the above scale, the decision maker issues scores for individual criteria, which are then placed in a square matrix (Table 9).

Table 9. The level of significance of individual criteria in the AHP method

	Producer	Technology	functional scope	Integration and incorporation	internationali zation	Customizatio n and expansion	System security policy	Help and support
Producer	1,000	2,000	0.143	0.250	2,000	0.167	0.200	0.250
Technology	0.500	1,000	0.125	0.200	1,000	0.200	0.167	0.167
functional scope	7,000	8,000	1,000	4,000	9,000	2,000	2,000	3,000
Integration and incorporation	4,000	5,000	0.250	1,000	3,000	0.200	0.333	0.200
internationalization	0.500	1,000	0.111	0.333	1,000	0.143	0.167	0.167
Customization and expansion	6,000	5,000	0.500	5,000	7,000	1,000	3,000	3,000
security policy	5,000	6,000	0.500	3,000	6,000	0.333	1,000	1,000
Help and support	4,000	6,000	0.333	5,000	6,000	0.333	1,000	1,000

Source: own elaboration

With the matrix created in this way, the ranking was started – the criteria groups were classified in accordance with the data contained therein. The further part of the article presents a step-by-step form of a network of actions that was undertaken to achieve the main objective of the study, i.e. to select the best GIS class system in terms of all criteria. In order to precisely classify the systems, four iterations of the algorithm must be carried out. Initially, in accordance with the assumptions of the AHP strategy, the expert evaluation matrix was multiplied by its second, mirror instance (i.e. by itself – it was raised to the second power), thanks to which the following result was obtained, also presented in the form of an 8x8 matrix:

$$\begin{bmatrix} 8 & 11.926 & 1.087 & 4.821 & 11.902 & 1.505 & 2.186 & 2.345 \\ 5.875 & 8 & 0.721 & 3.692 & 8.125 & 1.027 & 1.683 & 1.807 \\ 72.5 & 99 & 8 & 45.35 & 96 & 10.519 & 18.567 & 19.383 \\ 17.417 & 27.2 & 2.363 & 8 & 25.85 & 3.173 & 4.1 & 4.417 \\ 5.968 & 8.27 & 0.712 & 3.484 & 8 & 0.969 & 1.529 & 1.62 \\ 68.5 & 94 & 7.01 & 40.833 & 86.5 & 8 & 14.867 & 15 \\ 37.5 & 54.667 & 4.381 & 19.117 & 49.833 & 5.49 & 8 & 8.35 \\ 43.333 & 61.333 & 4.571 & 20.2 & 52.333 & 5.39 & 8.133 & 8 \end{bmatrix}$$

For the data set obtained in this way, the eigenvector was calculated. The calculation results are presented in table 10.

Table 10. Calculated eigenvector for the evaluation matrix

8	11,926	1.087	4.821	11.902	1.505	2.186	2.345	**8**	**0.021739**
5.875	8	0.721	3.692	8.125	1.027	1.683	1.807	**8**	**0.021739**
72.5	99	8	45.35	96	10.519	18,567	19,383	**203**	**0.55163**
17.417	27.2	2.363	8	25.85	3.173	4.1	4.417	**8**	**0.021739**
5.968	8.27	0.712	3,484	8	0.969	1.529	1.62	**8**	**0.021739**
68.5	94	7.01	40,833	86.5	8	14,867	15	**117**	**0.317935**
37.5	54,667	4.381	19.117	49,833	5.49	8	8.35	**8**	**0.021739**
43.333	61,333	4.571	20.2	52,333	5.39	8.133	8	**8**	**0.021739**

Source: own elaboration

The values in the first, highlighted column of data are mapped to the sums of subsequent rows of the matrix shown. On the other hand, the data placed in the right, bold column form the eigenvector of this matrix. Since for the penultimate column $\sum$ = 368, eigenvalues *were* obtained by dividing the value of the sum of each row by the mentioned quantity (here: 368). The estimation of the mentioned vector of eigenvalues completes the first iteration of the considered algorithm. In the next pass, the above matrix is multiplied (multiplied) by itself, which results in the following values:

$$
\begin{bmatrix}
654.5546 & 932.7877 & 76.7028 & 362.5412 & 878.1439 & 99.2329 & 154.6408 & 161.5433 \\
470.8308 & 672.4317 & 55.2636 & 259.011 & 631.8486 & 71.4253 & 110.6826 & 115.5921 \\
5361.1515 & 7668.6807 & 633.3805 & 2951.0988 & 7225.0809 & 822.4163 & 1268.9209 & 1327.6839 \\
1326.5647 & 1883.9362 & 155.1516 & 742.7794 & 1778.6798 & 201.1367 & 315.9461 & 330.1743 \\
450.2885 & 642.7785 & 52.9708 & 248.8588 & 605.4309 & 68.6494 & 106.5141 & 111.3505 \\
4591.4029 & 6573.6629 & 546.1672 & 2537.0964 & 6217.3923 & 713.2201 & 1097.6385 & 1150.9941 \\
2607.0508 & 3715.9079 & 307.5807 & 1453.6298 & 3514.4384 & 400.4572 & 623.4263 & 652.7569 \\
2723.4061 & 3884.147 & 322.8683 & 1523.7413 & 3683.9208 & 421.983 & 655.9174 & 687.8077
\end{bmatrix}
$$

An 8x8 matrix was obtained with a large increment of individual values. Below (Table 11), the data is presented in tabular form, detailing the column of the sum of rows and the eigenvector values for the obtained matrix. This step is analogous to the one described previously. The value of the partial sums of the individual rows of the matrix (allocated in the penultimate column) is $\sum$ = 92593.4707. The last column is the vector of the newly created matrix. An 8x8 matrix was obtained with a large increment of individual values. Below, the data is presented in tabular form, detailing the column of the sum of rows and the eigenvector values for the obtained matrix. This step is analogous to the one described previously. The value of the partial sums of the individual rows of the matrix (allocated in the penultimate column) is $\sum$ = 92593.4707. The last column is the vector of the newly created matrix.

Table 11. Calculated eigenvector for the next evaluation matrix

654.5546	932.7877	76.7028	362.5412	878.1439	99.2329	154.6408	161.5433	3320.15	0.035857
470.8308	672.4317	55.2636	259.011	631.8486	71.4253	110.6826	115.5921	2387.09	0.02578
5361.1515	7668.681	633.3805	2951.099	7225.081	822.4163	1268.9209	1327.6839	27258.41	0.294388
1326.5647	1883,936	155.1516	742.7794	1778.68	201.1367	315.9461	330.1743	6734.37	0.07273
450.2885	642.7785	52.9708	248.8588	605.4309	68.6494	106.5141	111.3505	2286.84	0.024698
4591.4029	6573.663	546.1672	2537.096	6217.392	713.2201	1097.6385	1150.9941	23427.57	0.253015
2607.0508	3715.908	307.5807	1453.63	3514,438	400.4572	623.4263	652.7569	13275.25	0.143371
2723.4061	3884.147	322.8683	1523.741	3683.921	421,983	655.9174	687.8077	13903.79	0.15016

Source: own elaboration

The rightness of the next step of the algorithm that has just been implemented should be justified here. The idea of this methodology is to implement an iterative approach in eigenvector estimation. This vector determines the value of the significance function for each of the considered criteria. Hence, it was decided to perform the next (second and third step of the algorithm), thanks to which the trend of the calculated eigenvectors can be noticed. Thus, having a basic factual basis consisting of two eigenvectors, the difference that distinguishes subsequent values of vectors was calculated:

$$
\begin{bmatrix}
0,02173913 \\
0,02173913 \\
0,55163043 \\
0,02173913 \\
0,02173913 \\
0,31793478 \\
0,02173913 \\
0,02173913
\end{bmatrix}
-
\begin{bmatrix}
0,035857 \\
0,02578 \\
0,294388 \\
0,07273 \\
0,024698 \\
0,253015 \\
0,143371 \\
0,15016
\end{bmatrix}
=
\begin{bmatrix}
0,014118119 \\
0,004041151 \\
0,257242361 \\
0,050991363 \\
0,002958524 \\
0,064919379 \\
0,121632188 \\
0,128420395
\end{bmatrix}
$$

Since there are slight differences between the corresponding relative elements of the computed vectors, the algorithm is terminated at this point, i.e. after the second iteration. This is consistent with the AHP idea, and the eigenvector values calculated in the last step have been rounded to the nearest thousandth and are approximated below:

$$
\begin{bmatrix}
0,035857 \\
0,02578 \\
0,294388 \\
0,07273 \\
0,024698 \\
0,253015 \\
0,143371 \\
0,15016
\end{bmatrix}
\approx
\begin{bmatrix}
0,036 \\
0,026 \\
0,294 \\
0,073 \\
0,025 \\
0,253 \\
0,143 \\
0,151
\end{bmatrix}
$$

Before the end of the algorithm, the third and fourth iterations were carried out. For illustrative purposes, the next matrices for the third and fourth AHP run are placed below (Table 12 and 13):

Table 12. The results of the third pass (iteration) of the AHP algorithm

3453917,347	4927875	407021,758	1915789	4650416	528734.5	821160.2409	859152.4784
2480473.282	3539036	292308.433	1375817	3339753	379716.4	589716.0504	616999.4448
28383668.86	40496882	3344910.54	15743257	38216792	4345187	6748158.603	7060403,847
7019765.302	10015353	827231,832	3893796	9451549	1074610	1668979.386	1746201.194
2380246.034	3396033	280499.593	1320242	3204826	364379.7	565898.6656	592082.0981
24464639.25	34905482	2883133.55	13569658	32940581	3745384	5816588,559	6085770.879
13857539.4	19771278	1633058.76	7686513	18658342	2121439	3294716,458	3447177.721
14543192.13	20749583	1713886.55	8066893	19581736	2226466	3457807.133	3617832.385

Source: own elaboration

Table 13. The results of the fourth pass (iteration) of the AHP algorithm

970326782 44969.484	138441952 366948.36	114348764 77680.184	538213425 10034.891	130648054 673509.3	148544572 95247.072	230696948 12326.031	2.41372E+1 3
696847461 59730.055	994231271 72264.031	821204236 6703.9424	386522010 71260.633	938258810 39311.188	106678399 95695.33	165676744 75570.758	173342886 04464,826
797403565 236610.5	1.13770029 24*10^15	939705204 26461.172	442297699 787854.69	1.07365092 34*10^15	122072248 482742.48	189584140 351511.84	198356517 004884.19
197212152 529143.03	281373614 729952.56	232405890 97879.938	109388125 771444.03	265533061 163132.5	301906486 69033.391	468875460 91592.359	490571116 15351.492
668697603 72711.852	954068294 12875.094	788030861 2021.7227	370908063 27178.469	900356897 03828.922	102369018 13694.16	158984065 14667.76	166340524 91351.289
687316986 714633.38	9.81E+14	809972989 47041.609	381235719 916627.69	9.25E+14	105219406 684545.64	163410857 171463.88	170972152 055241.97
389315946 242679.69	5.55E+14	458791804 75338.492	215942786 166716.84	524188056 628707.38	595992732 03762.016	925605706 31843.234	968435037 30640.844
408584423 331217.5	582950262 741160.13	481498861 82075.227	2.27E+14	550131780 947025.81	625490296 88251,484	971416859 40407.406	101636594 945140.48

Source: own elaboration

It was noted, however, that having both the input matrix and the eigenvector, there is no certainty that the results of the criteria ranking are in fact correct. This is due to the fact that the AHP algorithm is highly sensitive to input data. Although the data acquisition was carried out among a representative and independent group of experts using the Delphi method, the data may be inconsistent with the real ones. In order to eliminate any resulting errors, the algorithm is equipped with a very helpful mechanism validating both the input data set and the operational data set. Inconsistency Index and Consistency Index (because we are talking about them) allow you to determine the degree of data quality. The estimation of the mentioned ratios is presented below (Table 14):

Table 14. Vector table of the eigenvalues and partial sums of the AHP algorithm

[Verse 1]	0.0360	0.0260	0.2940	0.0730	0.0250	0.2530	0.1430	0.1510
[Verse 2]	28.00	34.00	2.96	18.78	35.00	4.38	7.87	8.78

Source: own elaboration

The first row is the vector of eigenvalues estimated in the second, final step of the algorithm for the input data matrix. It has been appropriately transposed to a horizontal

form. Directly below it is a second row, with subtotals. They were calculated on the basis of successive columns of data from the original – input matrix, for which criteria were compared in pairs.

Stage 2. Calculating the importance of individual criteria. The parameter value was calculated λ_{max} as follows:

$$\lambda_{max} = 0,036 * 28,0 + 0,026 * 34,0 + 0,294 * 2,96 + 0,073 * 18,78 + 0,025 * 35,0 + 0,253 * 4,38 + 0,143 * 7,87 + 0,151 * 8,78 = 8,56749$$

λ_{max} is the maximum eigenvalue (*eingenvalue*). Then, the *Consistency Index* (CI) was calculated. The following relationship was used here:

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

where: n – the number of considered criteria and the size of the input data matrix.

The formula above uses the maximum eigenvalue *that* was calculated in the previous step. In the considered case λ_{max}= 8.56749, and the "n" parameter takes the value of 8 (eight criteria and an 8x8 matrix). After substituting these data into the above relationship, the following was obtained:

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{8,56749}{8 - 1} = 0,08107$$

In order to validate the obtained CI data consistency index, Saaty , as the creator of the algorithm, proposes detecting the value of the CR index, i.e. the degree of consistency (*Consistency Ratio*). In the problem under consideration and in the nomenclature, CR is defined as the ratio of the data cohesion index (consistency) and the random consistency index RI (*Random Consistency Index*). The RI value provided by the author of the algorithm is closely related to the size of the matrix and the number of considered criteria. In the case of a larger set of features, their discriminant analysis should be considered or, alternatively, this value can be extrapolated. The relation defining the appropriate values of the "RI" coefficient depending on the size of the "n" parameter is presented below (Table 15):

Table 15. Selection of the RI parameter when calculating the consistency ratio CR
(*Consistency Ratio*) (Saaty, 2012)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	**1.41**	1.45	1.49

Source: own elaboration

For the present case, the value of the RI coefficient is 1.41. This is shown in the table with the appropriate specified frame contour with an index of 8 for the parameter n. The sought CR (*Consistency Ratio*) value was calculated as follows:

$$CR = \frac{CI}{RI} = \frac{0,08107}{1,41} \approx 0,05$$

It follows that the value of the data consistency factor is 0.05, i.e. 5%. If this result is less than 10%, the inputs match. Saaty explicitly informs that obtaining larger values indicates inconsistency in the pairwise comparison of alternatives. Therefore, all presented results are considered correct. This implies the final step in which the ranking results are interpreted, which was carried out for the main criteria for the selection of the GIS system. They constitute the first level/layer in the hierarchical structure of the tree describing the problem of choosing a solution. The order of the ranking results is determined by the individual values of the eigenvector. They have been deliberately presented here in an unordered (unsorted) form, so that the eigenvalues of the vector can be related to the appropriate group of criteria. As a reminder, before the visual presentation of the research results, a list of the estimated eigenvalues of each criterion is included.

The results of the ranking of individual criteria in the AHP algorithm. Decisions program was used in the comparative analysis. Notable screenshots from the SuperDecisions app presented in the form of tables, diagrams and charts below (Fig. 7):
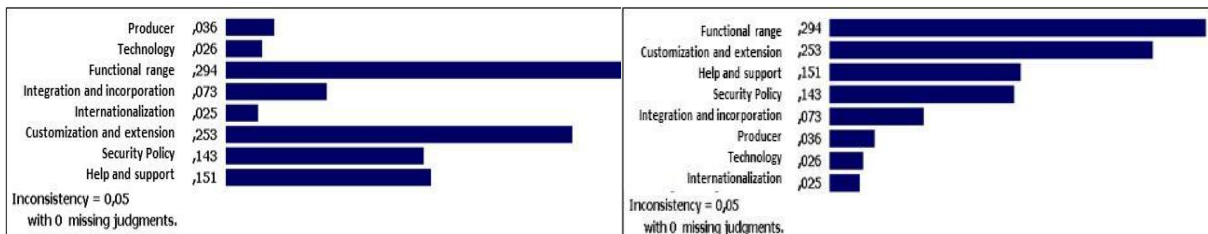

Fig. 7. Unsorted and ranked result data for the level of significance
of each of the considered criteria
Source: own elaboration

As can be seen from the attached charts, the most important from the point of view of decision-makers (experts) is the functional scope of the system (i.e. the richness, abundance of the solution in modules), the possibility of its expansion, help and support provided, and the security policy that is increasingly considered. It is also mentioned that all the results obtained in the research were confirmed by carrying out all the calculations twice and obtaining certainty as to the correctness of the results obtained. All calculations were also checked using advanced mathematical environments such as Statistica and MathCAD version 14, and special, dedicated expert software SuperDecisions. In addition, it is worth emphasizing that the presented results are fully consistent with the latest surveys presented in previous chapters. These are the results of reports from, among others, the Aberdeen Group and a survey conducted in Poland for the Manufacturing Systems Information magazine "MSI Polska", Trademedia International Holding, June 2018, p. 5.

The components of the criterion taken into account in a given study for the group under consideration are presented below. In addition, subsequent matrix structures filled with appropriate values of the feature significance function, coming from experts (Delphi method), were presented. Estimated values of the IC inconsistency coefficient and obtained results of ranking (prioritization) of individual features were also given for each of the examined feature matrices. The first separated group was tagged as

"Producer" due to the common information and their superior, connecting noun, which de facto characterizes each of the individual sub-criteria. The group of criteria includes the following units (information subcriteria – Table 16; comparison matrix – Table 17):

Table 16. Information subcriteria

"First System Overall"	Information regarding the manufacturer's experience, which confirms the presence of the given vendor's product on the market;
"First Production System"	Data showing the historical period when the first system was released for the manufacturing sector;
"The first system in Poland"	Information on the introduction of the first product to the domestic market;
"Origin"	The country where the producer is registered or from;
"Representation"	data specifying a physical unit representing the manufacturer's instance in Poland;
"Documentation"	checks not only the mere physical presence of the user's manual, but also its completeness as well as the abundance and accuracy of information;
"Website"	determines the layout of the manufacturer's website and the wealth of information that may be important from the customer's point of view;
"Number of implementations"	an index showing the manufacturer's experience, thanks to the indicator, which is the so-called *track record*, i.e. the number of implemented implementations – system implementations.

Source: own elaboration

Table 17. Comparison matrix for the component features of the first package of core criteria "Manufacturer"

	Origin	representation	website	Documentation	First system overall	The first system in the country	the first production system	Number of implementations
Origin		3.0	3.0	5.0	3.0	3.0	2.0	5.0
representation			3.0	3.0	2.0	2.0	3.0	2.0
website				5.0	1.0	1.0	1.0	4.0
Documentation					7.0	7.0	9.0	3.0
First system overall						1.0	2.0	8.0
The first system in the country							2.0	4.0
the first production system								5.0
Number of implementations								

Source: own elaboration

For the matrix under consideration, the calculated IC index is 0.06, which translates into an acceptable (below the 10% limit) result of 6%. Of course, on the diagonal of the matrix, by default, there are indices equal to one, and below it – the inverse values to the estimates given by experts. On the basis of the calculated eigenvector, a priority-sorted graph of the significance level of each of the component criteria was created. Above each ranking, there is the main objective of the study, the considered components in the format Goal > current subcriteria (here: Goal: Selection of the GIS system > Manufacturer) and the value of the consistency coefficient of the decision maker's assessment IC, which, as mentioned, is 0.06 in this case (Fig. 8 and 9).
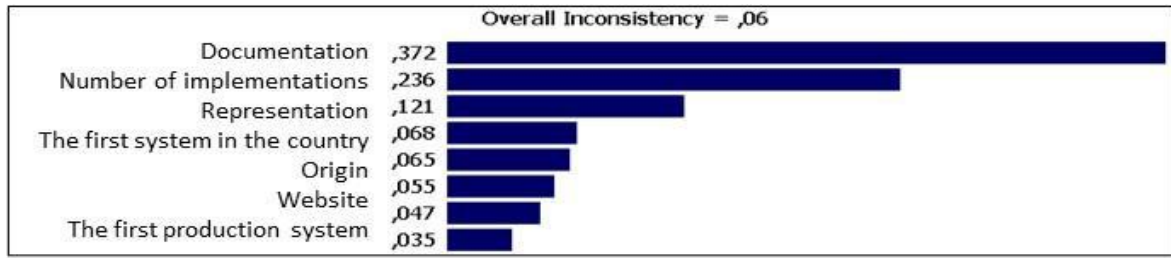
Fig. 8. Priorytetyfor the constituent characteristics
of the first main criterion – "Manufacturer"
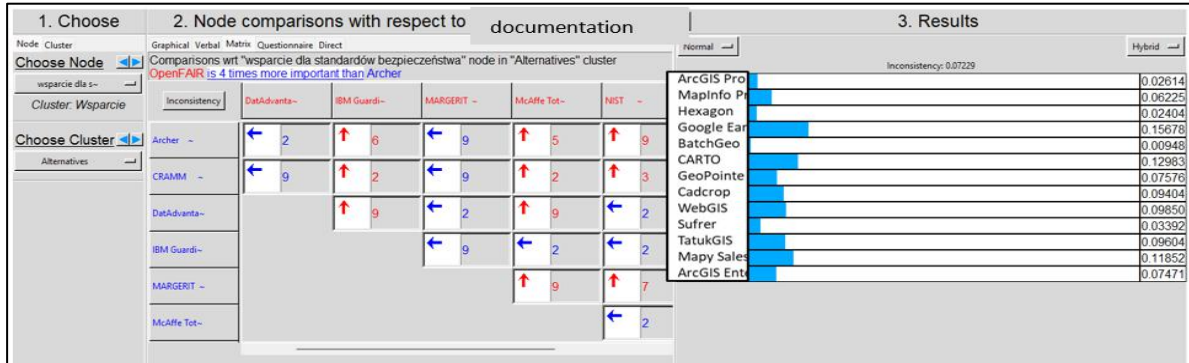Source: own elaboration

Fig. 9. Comparison of GIS in terms of the documentation subcategory
Source: own elaboration

For the remaining groups of the criterion, the results are as follows (Fig. 10):
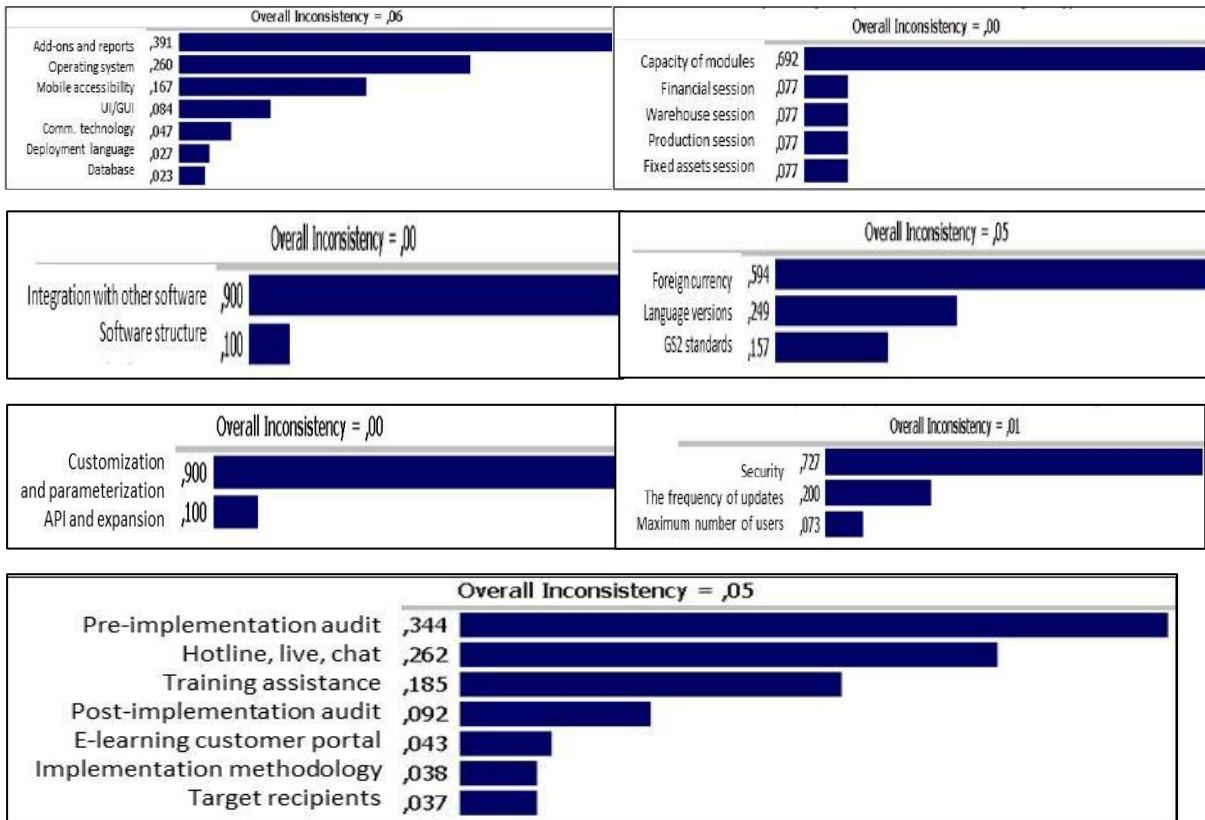

Fig. 10. Priorytetyfor the constituent features of the other seven main criteria
Source: own elaboration

The next step in the implementation of the algorithm is a mutual comparison of the considered systems in relation to each of the adopted criteria. Hence, for each of the eighteen features, tests were carried out to determine the value of the function of realization (or in other words, the degree of fulfillment) of a given criterion by the tested system. Since the actions taken so far were aimed at prioritizing the criteria and sub-criteria in relation to each other, in the next steps, all the examined systems were summarized in relation to each of the eight groups of criteria considered (Fig. 11–14). The obtained results are presented – eigenvalues *for* each of the performed numerical calculations. The results presented in tabular systems contain the gradation of results taken into account. The gradation emphasizes the fact that the results presented have been ranked in the correct order. The systems evaluated based on a given criterion were sorted according to the resulting eigenvector value. The order was made according to the decreasing degree of their intensification/intensity, i.e. from the strongest to the weakest from the point of view of the estimated eigenvalue of the system.
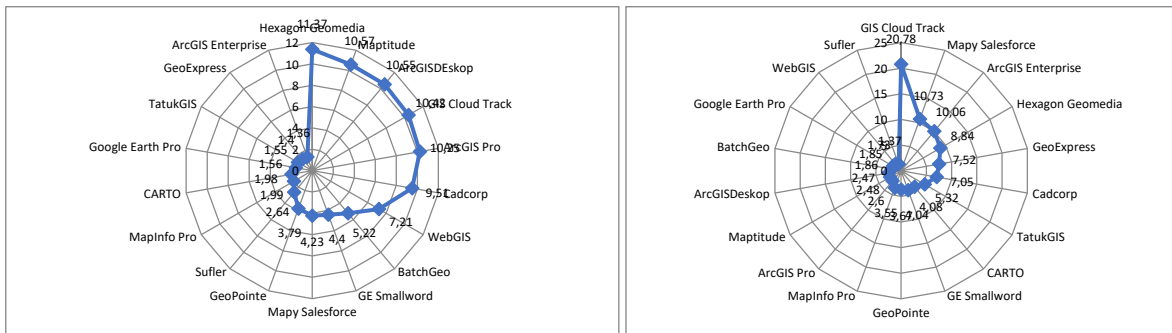

Fig. 11. Comparison of GIS systems against the first group of criteria,
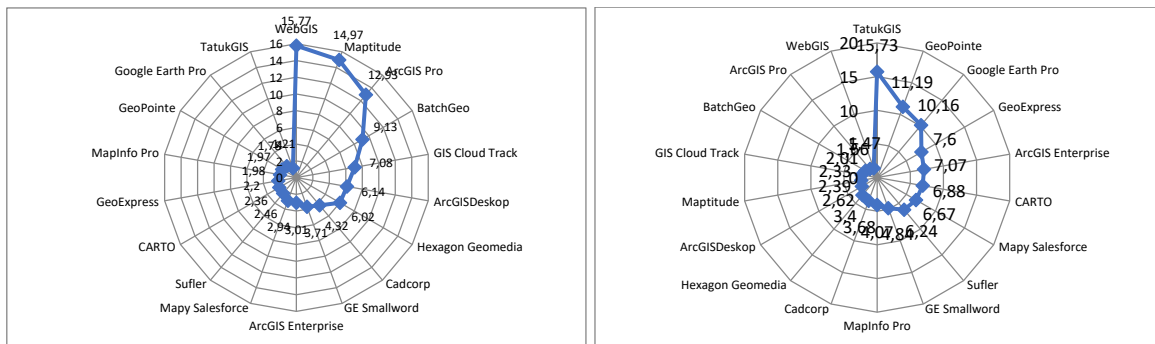i.e. "Manufacturer" and "Functional scope"
Source: own elaboration

Fig. 12. Comparison of ERP systems against the third group of criteria, i.e. "Integration and incorporation " and "Help and support"
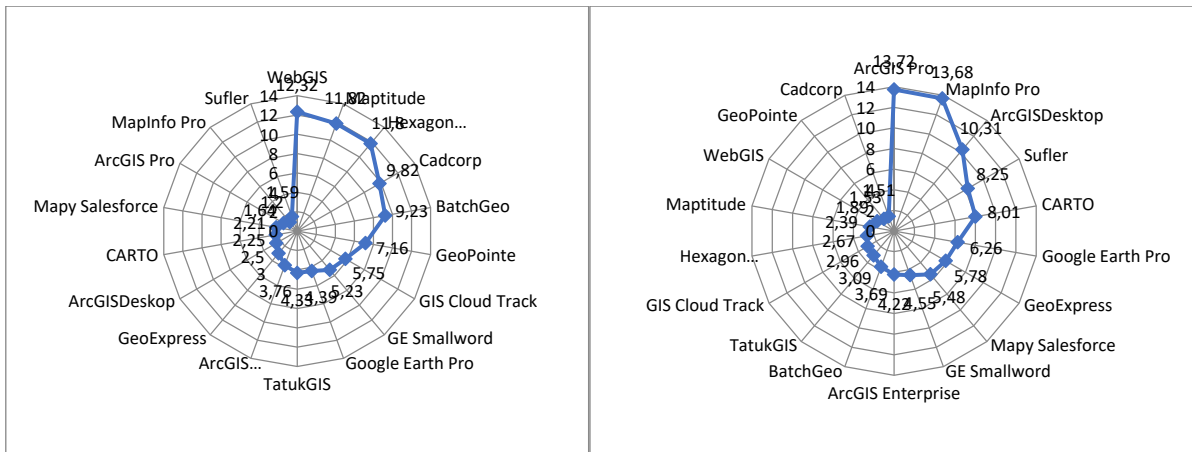Source: own elaboration

Fig. 13. Comparison of GIS systems against the fifth group of criteria,
i.e. "Customization and expansion" and "Internationalization"
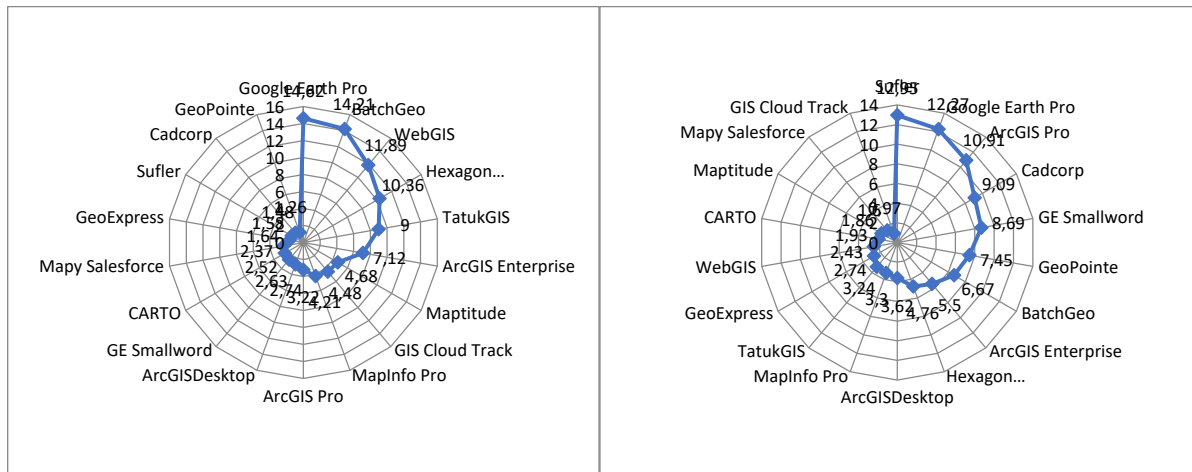Source: own elaboration

Fig. 14. Comparison of ERP systems against the seventh group of criteria,
i.e. "Technology" and "Security policy"
Source: own elaboration

For each of the eigenvectors presented in this way, the checksum coefficient of the individual components of the vector and the estimated value of the IC coefficient (*Inconsistency Index*) are attached. As you can see, its value, depending on the set of expert data, fluctuates, taking the level from 4% to 8.4%, which is obviously within the AHP acceptance limits. Of course, these fluctuations are not a completely random stochastic process, as they are highly dependent on the input data that will be taken from domain experts. Therefore, it seems reasonable to use the Delphi method in the work, which guarantees the consistency and representativeness of data from independent groups of decision-makers. However, it is worth bearing in mind that these fluctuations are not random, and the value of the deviation is represented by the Inconsistency Index (IC). As a reminder, it is emphasized that when the IC exceeds the value of 10%, then the process of data acquisition from experts should be repeated. Then, due to the variance between the individual pieces of information, the data are inconsistent and cannot be a representative carrier of the resulting information in the

considered problem issue (according to the assumptions of the AHP strategy). Below (Table 18) is a summary of the obtained eigenvectors of each group of criteria in relation to the eighteen tested GIS class systems. For each system, the value of the own index was presented, which was calculated when comparing the product with competitive solutions for the subsequent groups of comparative criteria considered.

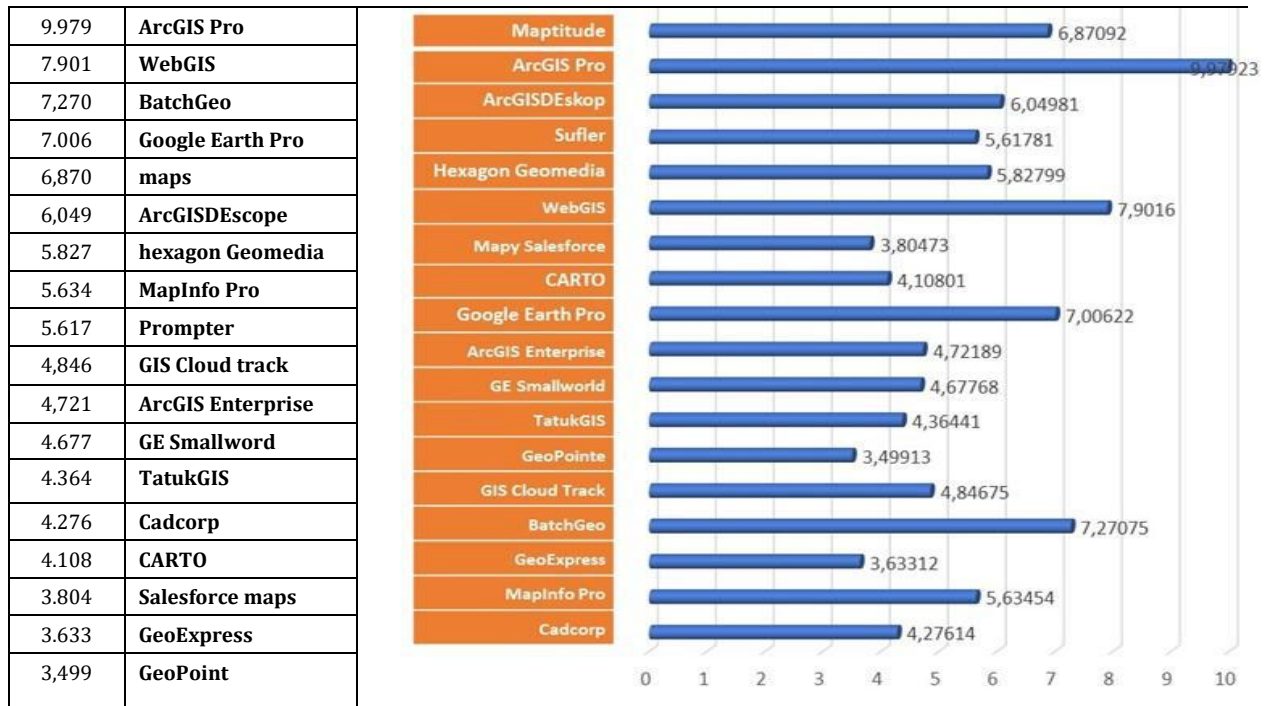Table 18. Obtained eigenvectors for the eighteen tested systems

	Producer	functional scope	Integration and incorporation	Help and support	Customization and expansion	internationalization	Technology	security policy
Cadcorp	9.51	7.05	4.32	3.68	9.82	1.51	1.48	9.09
MapInfo Pro	1.99	3.55	1.98	4.07	1.2	13.68	4.21	3.3
GeoExpress	1.4	7.52	2.2	7.6	3	5.78	1.64	2.74
BatchGeo	5.22	1.86	9.13	2.01	9.23	3.69	14.21	6.67
GIS Cloud track	10.42	20.78	7.08	2.33	5.75	2.96	4.48	0.97
GeoPoint	3.79	3.67	1.97	11.19	7.16	1.53	1.26	7.45
TatukGIS	1.55	5.32	1.21	15.73	4.33	3.09	9	3.24
GE Smallword	4.4	4.04	3.71	4.84	5.23	4.55	2.63	8.69
ArcGIS Enterprise	1.36	10.06	3.01	7.07	3.76	4.22	7.12	5.5
Google Earth Pro	1.56	1.85	1.78	10.16	4.39	6.26	14.62	12.27
CARTO	1.98	4.08	2.36	6.88	2.25	8.01	2.52	1.93
Salesforce maps	4.23	10.73	2.94	6.67	2.21	5.48	2.37	1.6
WebGIS	7.21	1.73	15.77	1.47	12.32	1.89	11.89	2.43
hexagon Geomedia	11.37	8.84	6.02	3.4	11.8	2.67	10.36	4.76
Prompter	2.64	1.37	2.46	6.24	1.59	8.25	1.58	12.95
ArcGISDEscope	10.55	2.47	6.14	2.62	2.5	10.31	2.74	3.62
ArcGIS Pro	10.25	2.6	12.93	1.66	1.64	13.72	3.22	10.91
maps	10.57	2.48	14.97	2.39	11.82	2.39	4.68	1.86

Source: own elaboration

The result vectors presented below are the searched solution that ranks the systems according to the assumed characteristics. The chart below (Table 19) presents the final results of the selection of the GIS class system based on the Analytic Hierarchy Process strategy and a wide, comprehensive set of comparative criteria.

According to calculations based on expert data, the best system in terms of the considered set of criteria is ArcGIS Pro (Table 20). It can be seen that it significantly differs from competing products, achieving an advantage over the second, WebGIS, equal to 2.07763 adopted function points. It is worth noting that the difference between the obtained results is not large, which indicates a very similar nature of the studied GIS systems. The final ranking of the tested systems after normalization of the results is as follows (Table 20).

Table 19. Validation and comparison of calculation results. Calculation results, obtained analytically and manually (which were then compared with those calculated in the Micfosoft Office Excel 2017 spreadsheet)

9.979	ArcGIS Pro	
7.901	WebGIS	
7,270	BatchGeo	
7.006	Google Earth Pro	
6,870	maps	
6,049	ArcGISDEscope	
5.827	hexagon Geomedia	
5.634	MapInfo Pro	
5.617	Prompter	
4,846	GIS Cloud track	
4,721	ArcGIS Enterprise	
4.677	GE Smallword	
4.364	TatukGIS	
4.276	Cadcorp	
4.108	CARTO	
3.804	Salesforce maps	
3.633	GeoExpress	
3,499	GeoPoint	

Chart values:
- Maptitude: 6,87092
- ArcGIS Pro: 9,97923
- ArcGISDEskop: 6,04981
- Sufler: 5,61781
- Hexagon Geomedia: 5,82799
- WebGIS: 7,9016
- Mapy Salesforce: 3,80473
- CARTO: 4,10801
- Google Earth Pro: 7,00622
- ArcGIS Enterprise: 4,72189
- GE Smallworld: 4,67768
- TatukGIS: 4,36441
- GeoPointe: 3,49913
- GIS Cloud Track: 4,84675
- BatchGeo: 7,27075
- GeoExpress: 3,63312
- MapInfo Pro: 5,63454
- Cadcorp: 4,27614

Source: own elaboration

Table 20. Ranking of the tested systems after normalization of the results

| The name of the GIS system	Position	Estimated value after normalization
ArcGIS Pro	1	1
WebGIS	2	0.791804578
BatchGeo	3	0.728588278
Google Earth Pro	4	0.702080221
maps	5	0.68852206
ArcGIS Desktop	6	0.606240161
hexagon Geomedia	7	0.584011993
MapInfo Pro	8	0.56462673
surfer	9	0.562950248
GIS Cloud track	10	0.485683765
ArcGIS Enterprise	11	0.473171778
GE Smallworld	12	0.468741576
TatukGIS	13	0.437349375
Cadcorp	14	0.428504003
CARTO	15	0.41165601
Salesforce maps	16	0.381264887
GeoExpress	17	0.36406817
GeoPoint	18	0.350641282
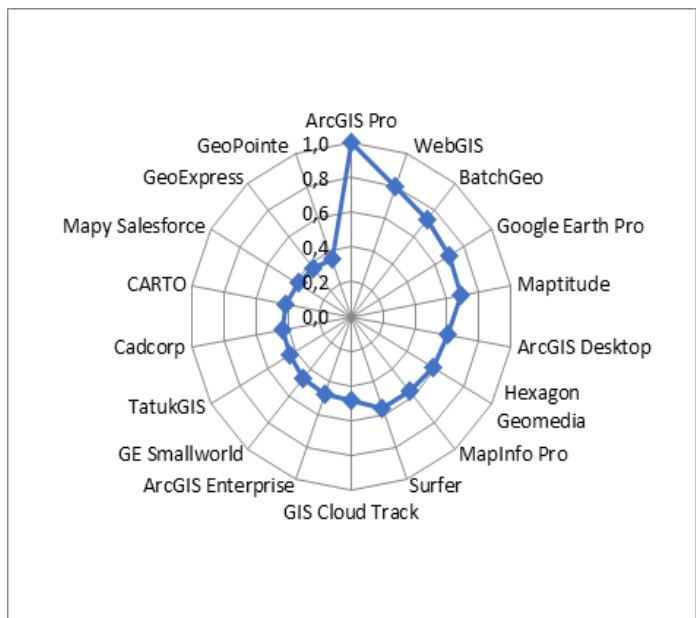
Fig. 15. Resulting radar chart of the order of GIS systems after being ranked against all comparison criteria
Source: own elaboration

Source: own elaboration

It is very important that the obtained results fully coincide with the initially assumed predictive results of the statement. The results obtained in the study are identical to those expected, which resulted directly from the acquisition procedure when familiarizing with the system. Already at the time of data acquisition, the advantage and dominance of certain solutions over competing products was noticed, while the study fully confirms the assumptions as to the order of GIS systems in the comparison. This is a key fact from the point of view of work. The AHP method, despite being sensitive to data and classified as a heuristic strategy, gives very good results that are fully representative. You can validate the results based on your knowledge of the domain of the study being dealt with. A full coverage of considerations is noticeable here, which were justified in an inductive way, proving numerically all conjectures.

Conclusion

The main purpose of this article was to analyze the GIS class systems available in the professional literature and the Internet and to perform a comparative analysis using the AHP method in order to select the best geoinformation solution in terms of selected criteria. It is also noted that out of the plethora of materials that have been known and ever encountered, the assessment method presented in this paper is rarely used. Few people evaluate the same set of objects (here: GIS systems) using several different, completely different approaches. Unfortunately, currently there is a noticeable trend in which methods dedicated to the adopted and defined assessment result are most often used, hence an innovative approach was used in the work, in which a set of eighteen systems was evaluated based on various strategies, the results of which were synthesized using the AHP method. In the comparison, the most important of the criteria were used, because the use of all of them (which were only a suggestion) did not have a major impact on the real comparison. It should be taken into account that the comparison of GIS with each other was based on the subjective assessment of the author. The results obtained in the work fully agree with the current state, which characterizes the considered set of GIS systems. At the same time, it is mentioned that the obtained results should be treated as advice and guidance in the decision-making process.

Acknowledgments

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