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GIS applications for modern-style military operations planning

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Abstract. The primary objective of the article is to reflect the practical necessity and possibilities of using GIS software for planning of military operations in the contemporary information environment. The results analysed by the GIS platforms can be used by the specialists in all fields of operational planning by providing the requested data that can improve the performance of operational planning.
The obvious need for the development process of the operational planning system in the context of the adoption of planning procedures appears as an opportunity, especially in the current stage of the reformation of the National Army.
The geographical characteristics of the area of operation are thoroughly analysed from all available geographical sources. Until now, the most effective method of determining the geographical features of the terrain in the area of operation was considered to be reading from printed topographic maps, which included a series of additional determinations and analyses that were carried out through complex and long-lasting procedures. Accordingly, this fact was not allowing quick decision-making, and often, erroneous analysis of the terrain could lead to incorrect deductions that required commanders of all levels to make wrong conclusions, accordingly to expose them by orders.

1. The geographic information system in the military domain

The operational planning group assists the commander in fully assessing the conditions that may influence military operations through an assessment of the situation in the area of joint operations and other areas of interest. The Joint Intelligence Preparation of the Battlespace (JIPB) performed by the joint intelligence structures contributes to the estimation through intelligence assessments, deductions and other intelligence products to support the decision-making process by the commander.

This estimate must take into account the analysis of the following factors:

- Geographical conditions. These are part of the JIPB and include analysis of the likely effects of significant terrain and infrastructure on operations.
- Meteorological and hydrographic conditions. They are also part of the JIPB and include the analysis of the likely effects of the atmosphere, weather and climatic conditions, hydrographic conditions on military operations.

Taking into account the fact that military actions can be carried out on land, in the air and on water surfaces, terrain analysis using GIS platforms will consist of studying terrain elements in all forms of existence (obtaining terrain analytical data) to favor the Informative Preparation of the battlefield, which in simpler language will be called Geo-information.

Geo-information – consists in the marking and overall description of the elements of the terrain and infrastructure, which can influence the operational-tactical activity of own troops, as well as the enemy in the conduct of combat activities.

1.1. Using GIS to define the confrontation environment

The integrated analysis of the enemy, the terrain and the confrontational environment in the area of operations within the Informative Preparation of the battlefield includes all the activities aimed at identifying the significant characteristics of the geographical environment that can influence the operations in any way. When defining the confrontation environment, in the initial phase of the geo-information process, information about the geography, terrain and meteorological situation in the area will be analyzed, as well as the infrastructure as a separate element, which in turn at the end of the process will report a string of data and estimates, necessary to go through the next step oriented in describing the effects of the confrontational environment on the operations. These analytical descriptions will later be studied by other elements of operational planning without the use of GIS, for the evaluation of the enemy and finally, for the determination of the probable courses of action of the enemy and being approved, will contribute to the elaboration of operational documents.

The description of the effects of the confrontational environment on operations offers the possibility to move to a new stage of operational planning, which through the use of GIS ensures the description of the effects of the confrontational environment on the operational capacity of the enemy and its own forces. As part of this analytical process, the terrain analysis will allow us to know the topographical situation for planning movement, masking, carrying out engineer works, research, radiolocation, etc., and the weather condition can tell us the real needs of training troops and equipment for the apparent conditions depending on the season and the location where these military actions will take place.

The terrestrial confrontation environment is the physical space of great variety, with discontinuities and fragmentations (vegetation, hydrography, relief) whose complexity is increased by the impact of meteorological factors.

The terrestrial environment is the main place of confrontation between the belligerents, actions in the terrestrial environment are influenced by: localities, mountains, forested areas, watercourses, areas with water improvement works, tall crops, etc.

The terrestrial environment is characterized by the increasing importance of urban areas, they occupy vast spaces, branch out and fragment the terrestrial space. Urban areas can ensure the protection of own troops against enemy threats, reducing the risk to which they are subjected and limiting losses.

The aerial confrontation environment is the physical-geographical environment for the use of air forces and represents the column of air located above the terrestrial environment, up to the lower limit of extra-atmospheric space.

For weather analysis, the direct effects of climatic conditions on the terrain and military actions are evaluated. From the category of needs analyzed on the basis of GIS, long-term or current estimates and forecasts can be made for:

a) The wind.

Wind regime and blowing speeds for the main directions of propagation; wind periods with anomalies and maximum speeds recorded.

b) Precipitation.

The total amount of precipitation recorded on the ground surface in the form of rain, snow, hail, hail or others, recorded over long observation periods and the probable estimates of their fall.

c) Temperature.

The average of ground temperatures recorded over long observation periods and their probable monthly average estimates.

The analysis of the complex confrontation environment includes the analysis of all the factors listed above to deduce the effects that can influence the operational capability of the enemy and own forces. The description of the confrontational environment results from the results of analytical procedures on the geographic environment and infrastructure, in combination with other tactical factors that have a direct impact on the conduct of operations in different environments and emerges from the study of terrain elements using GIS platforms and applications.

1.2. Geospatial data sources used

The analytical study of the land in the geo-information process will be carried out in the office, using all the credible data available, as well as additionally, if possible those collected or updated in the field. From the category of credible data, all previously recorded data from own sources and stored on memory devices can be used, as well as those recently obtained (from sensors or devices in the field) to be verified and processed. Other data sources can be considered the data uploaded from open sources (usually the Internet), obtained through the WMS and WFS viewing and downloading services. These services can be widely used only if the data viewed or downloaded through these services can have an appropriate verification of their actuality and veracity, as well as the most essential factor for obtaining them – the possibilities of connecting to the Internet.

For the acquisition and analysis of the data that will later be used for the Geo-information process, procedures from the branch of geography will be used, such as:

- Remote sensing and photo interpretation;
- Field measurements and observations;
- Scanning, georeferencing, vectorization.

The analysis and representation of geographic information about objects in the field, through the Geographic Information System platforms, is carried out using spatial data of planimetric and three-dimensional models, such as:

- The vector model;
- The raster model;
- The three-dimensional model.

For the full representation of the relief shape as well as to give the opportunity to understand how the terrain can influence the successful conduct of military operations, the three-dimensional model allows the 3D visualization of the relief forms, for these reasons the use of this model will be crucial and the factor of its use will be seriously taken into consideration, both at the elaboration of the geographical documents and at the analysis stage.

The vector data model represents any terrain feature rendered on a surface by point, line, or polygon. In this model the information about points, lines or polygons is coded and stored as a collection of X,Y coordinates. A point is represented by a single pair of X, Y coordinates. A line, or polygon, is represented by an ordered string of pairs of X and Y coordinates.

The advantages of using this model are:

- It is the most used model, having more application possibilities than the raster model; analysis programs based on this model have a greater spectrum of analysis and rendering possibilities; compact data structure; topology easy to achieve; superior graphics; the simple possibility of storing, retrieving, updating, and generating spatial data through attributes.

The disadvantages of using this model are:

- The techniques used are more complex; data use requires ongoing training; difficult combination of thematic layers; difficult simulation because each layer requires separate resources; display and plotting may be expressed with errors.

The raster data model represents an area of land as a matrix (grid) of uniform cells, each cell having a value. The value of a cell indicates the resolution of the object (or part of it) located at that position. A polygonal object is represented as a group of adjacent cells that render the area and shape of the object.

The advantages of this model are:

- Simple data structure; overlapping and combining layers is easier to achieve; simplicity, which is related to the possibility of performing spatial analysis; facilitates simulations without the need for increased resources; the graphic representation is done without additional processing.

The disadvantages of this model are:

- It is a big consumer of memory; in order to obtain quality, the use of high-resolution documents is required; not useful for representations of small linear elements; the quality of the graphical data presentation is inferior.

The three-dimensional terrain model is a digital representation of the relief surface in space, using points with horizontal X and Y coordinates along with the Z coordinate. The land surface is represented by a mathematical surface that approximates the topographic surface of the land.

The three-dimensional terrain model can be complexly represented using other overlaying materials, such as satellite images (from space), scanned raster maps or vector data, and the information combined into a single digital model can be used for various analysis purposes. The digital processing of this model allows the generation of contour lines, which, being superimposed on other materials to be printed on paper, can render the earth's surface in a two-dimensional plane.

Among the fields where the three-dimensional model can have an immediate applicability can be listed: the analysis of telecommunications systems, the analysis of visibility and passage possibilities, air navigation, ballistics, as well as in all other fields where it is necessary to know the altitude information at various points of the a surface.

The use of objects in 3D model for infrastructure objects (buildings), offers the possibility to see in perspective what will be the tactical surroundings, especially when planning and conducting military actions in the urban environment.

1.3. Programs and methods used

The Geographic Information System itself includes a variety of software and accessories that can perform the analysis and visualization tasks. All of the programs that allow these analyzes to be performed are those that work using accessible geographic data sets, in a common format with the ability to read coordinates and data attributes. The digital representation of terrain as well as analytical processing results must allow users to understand in a unique, standardized and easy readable format the meaning of analyzes by displaying a digital result and in some cases the conclusion once the image is perceived by the human eye.

Working in GIS requires an extremely high effort, both for professional users (developers), who operate the programs, and for ordinary users who view and analyze the final product. Thus, the transmission of an incomprehensible message from the developer to the user can be considered a thing done in vain, and the professional user, in turn, can get a yield of mistrust that will considerably diminish his professional capacity.

The processing of the analytical products that will be presented for viewing can be performed through any programs based on GIS platforms (ArcGIS Pro, ArcMap, QGis, Global Mapper, etc.), and the visualization can be performed by users, both through these programs (if they know them), as well as through other standard ways that computer platforms based on Windows, Linux, Android, MacOS, etc. The widespread use of web services allows today to view the final materials through web browsers, using the WEB-Gis network services.

For example, the QGis software offered by the company Open Source Geospatial Foundation (OSGeo), allows to easily process data obtained by remote sensing, to load and view maps and materials of databases from open sources, as well as to create servers of WEB-Gis visualization through QGis Cloud, which through a simple registration gives access to the developer user to upload data online that can easily be viewed and analyzed at another end of the world without complex requirements.

By other example, the Global Mapper software from the Blue Marble Geographics company offers another spectrum of analysis and visualization possibilities, among which the most effective are the high-performance possibilities of viewing the land in 3D space, the simple download of geo-referenced satellite images, the visualization of a portion of land through flight simulation, as well as other terrain analysis possibilities through simplified and fairly accurate methods.

The merging of the software allows the total coverage of operational analysis requirements and fulfills the tasks of geo-information fully. Of course, each of these software has the ability to perform these tasks individually, but since they were not specifically programmed to perform military tasks, they do not have their own and unique ability to perform all the processes in a simple and pleasant way. Also, due to the complexity and the pressing requirements for geographic and IT knowledge, most simple users find it very difficult or impossible to operate these programs. Precisely for these reasons, the programs are designed only for processing by specialists and the final result needs to be exported or loaded into programs or browsers that can be operated by any of the users, without special training or knowledge.

For operational analysis, the representation of the final product will be standardized by allied symbols or additional information supported by a legend, since not all analysis procedures give the final explanation in military symbols (eg, areas seen and not seen from the point of view). Also for other cases, in the legend will be necessary to indicate, which mark is the value of the visible surface, or which is invisible, etc. In other situations, such as the analysis of favorable areas for the landing of helicopters, the same surfaces will generally constitute areas that satisfy all the conditions necessary for the safe landing of propeller-driven aircraft. But their marking can be represented by a random symbol, supported by other military symbols that will supplement the necessary explanations in this regard.

In general, military symbols and characters will only be used for the rendering of the tactical situation that will be used by the planning element, and it is not necessary to appear the mandatory in the analytical rendering of the results of the geographical survey of the terrain, according to the operational standards of planning.

In order to analyze the possibilities of GIS software and applications for geo-information, each of the tools of the accessible programs needs to be studied separately through which it will be related for deep understanding of the possibilities that can cover the analysis needed to ensure the operational planning process.

Taking in account that ESRI's ArcMap software is considered one of the most popular military analysis software due its special Military Tools for ArcGIS add-in used to simplify defense analysis workflows and mission-focused information. As well, the Military Tools for ArcGIS provides fundamental tools for coordinate conversion, distance and direction calculations, plotting and reference grids, military symbology in ArcGIS Pro, and visibility analysis. It contains add-ins for ArcMap or ArcGIS Pro and a Python geoprocessing toolbox that make the tools accessible as system tools in any ArcGIS project.

From the basic analytical functions they can perform, they can be used:

a) Enter coordinates and quickly convert them between several standard formats
b) Dynamic creation of geodetic lines, circles, ellipses and radius rings – the general "Distance and Direction" function.
c) Distribution of non-uniform surfaces into uniform reference surfaces – the general "Gridded Reference Graphic (GRG)" function.
d) Performing interactive analysis of linear and radial line of sight – the general "Visibility" function.
e) Rapid creation of standard military symbols, especially in ArcGIS Pro - General "Military Symbol Editor" function.

1.4. Description of the possibilities of other types of GIS applications

The analysis of the visibility in the locality is a very important procedure, which analytically allows to choose an observation post, optimally located to have the best visibility from the infrastructure and urban planning. The Viewshed tool of ESRI's City ENGINE application allows determination of the visible area from an observer point to a point of interest. The tool colors areas that are visible (default green) or hidden (default red) from the observer. The analysis object is usually activated in the platform via the Scene Editor function.

The View Dome function provides information about the contribution of each scene layer to the visibility of the geometry in the specified field of view. This information is presented as a horizontal bar chart and as a table in the Inspector when the Analyzes object is selected. The table provides the information as percentages of the specified field of view and as solid angles expressed as steradians. In addition to the layers defined in the scene editor, an additional category Panorama is displayed. Panorama applies to all non-geometric areas in the field of view, including the sky and areas below the horizon not covered by terrain or geometry.

This function with its specificity can and needs to be used not only for the visibility between points analyzed, but also for the possible radio signal coverage in urban regions. Each building in the neighborhoods presents an obstacle to direct radio signals, so the program can identify the main obstacles and the most optimal locations to place the devices of communication to have a better signal from the transmitter to the receiver. Visibility in this analysis favors to understand the percentage of the area visible compared to the area without visibility, not only by delineating the areas seen and not seen, but also for identifying the sectors of tall buildings where other stations may be placed for conjugate observation or reserve observation stations can be installed.

For rural areas, this application is not so effective, because the placement of observers on low houses in small areas does not present any advantage and does not contribute significantly to the reduction of the radio signal.

Road network analysis in the ArcGIS *Network Analyst* extension allows solving the common network problems, such as finding the best route in a city, finding the nearest emergency facility, identifying a service area around a location, serving a set of tasks with a group of vehicles, or choosing the best routes for facilities in the area of operations.

Network Analyst can find the best way to get from one location to another or to visit multiple locations. Locations can be specified interactively by placing points on the screen, entering an address, or using points from an existing feature class or feature layer. If they are more than two locations to visit, the best route can be determined for the order specified by the user. Alternatively, Network Analyst can determine the best sequence to visit the locations, which is known as solving the time and resource optimal route problem.

Allocation of locations helps to choose facilities from an available set of operations based on their potential interaction with demand points. The analyzed objective can influence the minimization of the total distance between demand points and facilities, to maximize the number of demand points covered at a certain distance from facilities, or to relate the road network that will optimize travel in an environment of nearby facilities.

This application of ArcGis and QGis software can work offline if a vector database of road networks is available. The user that operates the software can analyze the optimal travel routes through this application, in case an urgent decision is required to move a vehicle or a column in emergency mode. Previously, this procedure was carried out on the map with the help of the curvimeter, and the choice of the route was often concluded visually, taking into account the most advantageous roads, or based on several route calculations, which finally resulted in the choice of the most efficient from the point of view for mileage and driving conditions. For online analysis with an Internet connection, the QGis software offers an alternative route selection solution with the same principle based on the Online Routing Mapper application, which allows performing the same procedures, only from the road network provided on OpenStreetMap or OpenTopoMap maps and in this case, the need to have the road network loaded into the software disappears.

The road slope calculator offered by the QGis software allows the calculation of the longitudinal slope of paths and roads, based on a 2D vector line layer and a DEM. To calculate the slope, the initial vector layer will be segmented, and the value entered by the user determines the length of these segments. The end of the survey is represented as an "angular value", with the longitudinal slope of each segment, shown as a percentage in the attribute table or included in the layer labeling.

This application allows you to easily calculate the maximum slope angles on some sections of land or road, on which the movement of the technique is planned. Separately from the practical method based on GIS applications, this procedure can be performed by complex long-term analitic calculations, after the initial estimation of the route and the calculation of the road segments emerging from the map scale. Few intermediate problems creates the determination of the altitude of the initial and final points of the road segments, which also determines the slope angle by the formula of the right-angled geometric triangle. With the help of the software, this process is automated and is carried out in a few seconds, allowing users to draw conclusions about the accessibility of the chosen route and any apparent obstacles when traveling with heavy equipment, military vehicles or even on foot. Having the Network Analyst app with the road network layer already loaded and processed this road slope analysis app can supplement it to provide users with the safest and most optimal travel paths. And in the absence of them, it can provide conclusions on how to proceed to pass these complicated sectors of movement.

The Radio Signal Coverage Analysis offered by the Global Mapper software allows the calculation of the areas where the radio signal transmitted from a safe transmitter will reach the receiver based on the principle of direct visibility and the absence of natural obstacles. This procedure allows, by centrally installing a point on the three-dimensional model of the terrain, to see additional parameters (the distance of the transmitter, the curvature of the Earth, as well as other frequency parameters in the field of communications) within a set radius. All areas within the selected range that have a clear line of sight to the transmitter are colored with a user-specified color.

The Receiver Elevation section allows the user to specify the minimum height above ground or sea level from which the transmitter must be visible for the point to be considered visible. For communications or radar mission analyses, specifying the elevation above the ground is required, but specifying an elevation above sea level may be useful for aviation purposes.

Optionally, it can be specified that the receiver elevation should be calculated based on an elevation angle relative to the horizon from the transmitter. This is useful if there is a radar antenna that is pointed up at a certain angle and the user wants to identify where the signal can be seen. Finally, a transmission angle range can also be specified for a beam generated from the transmitter. The viewport will then depict where that beam would hit the ground surface (or some user-specified distance above the ground surface).

In this analysis procedure, several factors are not taken into account, such as: natural and infrastructure obstacles, jamming signals or other parameters such as refraction from the ionosphere or reflection from other objects on the ground.

1.5. Conclusions obtained after practical operations and recommendations

Based on the results obtained aster many case study operations, it can be concluded that the use of GIS software offers a very wide spectrum of analytical possibilities that in many cases cannot even be carried out by classical methods using the map or other materials typed on paper. By most, the results obtained were deduced in very short terms using minimal technical or informational resources. In the same context, a single study using GIS programs can be carried out by a person who replaces a group of personnel in the materialization and analytical deduction of the result.

At the same time, during the analysis some of difficulties were detected in the use of GIS software. Some of these were based on the impossibility of working on occasional computer stations, for the reasons that free licensed powerful software is not available, and licenses are very expensive, so practically it is very costly to purchase them just for replacement of analytical job. Moreover, due to the huge prices, even some state institutions in the field of security and defense cannot afford to procure them, resulting from their own development priorities. At the same time, the use of free platforms such as QGis offers a fairly wide and efficient spectrum of data analysis, while also contributing to the possibility of creating maps and schemes that can be easily published online, if they do not have classified materials.

Referring to the pragmatic results of planning operations obtained in a different spectrum of activities, several conclusions and recommendations were drawn that may require special attention in the use of GIS platforms in the future:

1) All GIS software offers similar data analysis, visualization and editing functions, but how to use them has a specific content as a method and result, which sometimes calls into question the rationale for using or choosing the preferred software. Such cases were encountered in several analyses, when the result generated by software did not fully satisfy the expected result, so it was resorted to the use of another type of software available.

2) The use of GIS software does not offer the possibility of making deductions or obtaining analytical results as a whole, but for different domains separately. For these reasons, GIS software operators need to have special knowledge in the field of operational planning, tactical skills, or to work directly in the presence of a specialist of the geography or topography fields, in order not to make mistakes.

3) Using multiple GIS software at the same time is very beneficial because, first of all, each one has its own interface and tools that other software may not have. At the same time, due to hardware requirements, licenses or other factors of the computer components use it may occur various errors or impossibility of installing plug-ins, while their importance of use could represent the vital necessity for the processing of geospatial information.

4) The use of information from open sources offers a valuable opportunity to reduce the time of data creation, visualization or analysis, but at the same time this data, not being verified or being downloaded from only one unreliable source, may jeopardize the completeness of information required and the correctness of its displaying. Completing the attributes and meta-data largely depends on the human factor and in some cases, the data being added incorrectly can lead to wrong estimates of the situation and in some cases it may result to the cost of human lives.

5) The use of GIS software should not be used for decision-making, but should be used for direct input into decision-making. As a rule, decision-making is a process based on the human factor, because artificial intelligence systems at the moment have not evolved so far. Generating results based on GIS platforms for all possible areas of military planning can help commanders at all levels to make decisions and in some cases even influence the change of initial, apparently spontaneous opinion.

6) The training of specialists in the field of GIS is a long-term process and due to the complexity of the software and the need for specific knowledge in the field of geography, cartography, topography, remote sensing and other similar fields, so they cannot be operated by any unprepared personnel, especially in limited terms. For these reasons, the learning and motivation of GIS specialists needs to be a continuous process that would fully capitalize on expectations at the required time.

7) The preparation of data and the generation of predefined functions such as the models from the Arc Toolbox of the Arc Map software, could considerably reduce the operating time of some analyzes and would allow the generation of results based on standard operating procedures, without cyclic presetting of analytical data processing modules. At the same time, these models can be used simultaneously at several stations by several operators, who would simultaneously work on the final product to expedite the achievement of the expected results.

8) In many situations, using only GIS software does not fully provide the expected result. For these reasons, knowledge of other graphic design software or Microsoft applications is beneficial. And the installation of add-ons, plug-ins and other extensions with analytical functions is crucial because the basic functions pre-set in the software itself do not fully solve the apparent problems.

9) No matter how complex and expensive the use of GIS software might be, the operability, precision and range of analytical results offered fully cover and justify the rationality of investing in their development. In addition, the era of information technologies tends to expand the use of GIS in all fields of activity, the military not being an exception, especially in its contribution to regional security and the defense of the state as a special task.

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