



GIS APPLICATION IN MILITARY VEHICLES' ROUTE PLANNING

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Abstract

Military operations and activities rely on accurate and reliable geospatial information to ensure effective command, control, surveillance, and coordination. Through the integration of diverse data sources and advanced analytical tools, Geographic Information Systems (GIS) facilitate precise mapping, modelling, and visualization, thereby supporting informed and data-driven decision-making. The military application of GIS enhances planning and operational efficiency, providing a significant strategic advantage on the battlefield. This paper examines the application of GIS in the planning and utilization of transportation infrastructure, with particular emphasis on its use for military purposes. The objective of this study is to explore the potential of GIS in supporting the planning of military vehicle routes along existing road networks.

Keywords: military planning, GIS software, road network, cross-country mobility

1 Introduction

A Geographic Information System (GIS) can be broadly defined as an integrated system designed to store, manage, display, and analyze spatial data [1]. By combining satellite imagery, aerial surveys, and ground-based measurements, up-to-date digital models of the operational environment can be created in GIS. These models are indispensable in military operational planning, providing accurate data needed for mapping, intelligence gathering, and scenario modelling, i.e., ensuring accurate, timely, and data-driven decisions [1, 2]. The GIS environment not only processes geographic data in standard formats but also represents terrain and analytical results in a clear, standardized, and visually intuitive way. Well-designed map products, 3D views, and dashboards enable users to quickly interpret outputs and draw operationally relevant conclusions, thereby shortening the decision-making cycle [2, 3]. In military operations, GIS provides commanders at all levels with comprehensive terrain analysis, real-time situational awareness, and strategic intelligence, helping them understand both the physical and environmental dimensions of the battlespace [2]. This is crucial for mission planning, force protection, and the synchronization of maneuver and fire support. As part of this analytical process, terrain analysis provides insight into topographical conditions for planning movement, camouflage, engineer tasks, reconnaissance, and radiolocation, while meteorological information highlights seasonal and regional factors that influence personnel and equipment requirements [2]. In GIS, different datasets can be overlaid to permit spatial analysis of environmental, infrastructural, and socio-economic variables, enabling assessments of how land use, terrain, and infrastructure interact with national security and military operations [1]. Overlay analysis underpins the derivation of composite mobility and risk layers that are essential for military decision-making. The integration of diverse geospatial data and advanced analytical techniques allows a complete understanding of terrain, road networks, and operational challenges.

As reliable geospatial information is the backbone of effective command, control, and logistics, GIS-based modelling and route optimization play a crucial role in enhancing the efficiency and safety of military vehicle movements.

This paper provides an overview of GIS applications in the military planning process, the factors by which tactically important roads are graded and considered and the importance of contemporary software in route planning. Basic terms like terrain passability are defined because terrain analysis, as part of this analytical process, provides insight into topographical conditions for planning movement. A short overview of route planning methodologies with common methods of analysis for reaching optimal route such as Dijkstra's algorithm, cost-surface analysis and AMIS method are explained, with emphasis on military-specific activities these methods need to account for. Finally, a brief overview of obstacles and challenges is provided, as is a proposal for future research and data gathering.

2 GIS in military planning

The efficacy of GIS in military planning depends on the quality, resolution, and integration of spatial data. Typical sources include satellite remote sensing, airborne imagery, existing topographic and thematic maps, surveys, and field measurement data [1-3]. Very useful are also airborne LIDAR Data for gathering precise digital terrain models, surfaces and hidden or masked military structures. These datasets are represented using vector and raster models, often complemented by 3D terrain models that capture relief, built-up areas, and infrastructure such as road networks and bridges. Analytical layers may incorporate vegetation cover, hydrological features, soil and geology, and transportation networks, each of which affects cross-country mobility for different types of military vehicles [1, 2]. The Operational planning group supports the commander in assessing conditions affecting military operations through Joint Intelligence Preparation of the Battlespace, which analyses geographical, meteorological, and hydrographic factors [2]. During mission planning, it is very important to ensure force protection that should be planned, coordinated, and integrated within the overall activity/operation [4]. The Operational planning group consist of several units: intelligence, operations, logistics and communications. Intelligence is responsible for providing accurate, timely, relevant, and predictive information about enemy placement, possible movements, and places of attack. Operations are ensuring unity of effort and the most effective use of one's own resources. Logistics define routes of supply and plan recovery points. Communications define relay station points and communications plans. All those groups are preparing layers that overlay in GIS. The layers collection is shown in figure 1. Within this process, GIS platforms are used to prioritize terrain and route analysis, identify features that influence friendly and enemy movement, and optimize land routes.

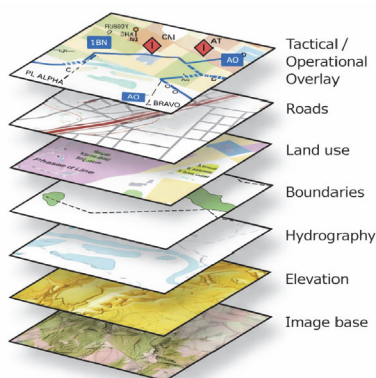


Figure 1 Layers collection in GIS

2.1 Identification of tactically important roads

Identification of tactically important roads is essential to provide fast and safe movement of troops and equipment. Route planning on existing infrastructure is very important because vehicles carrying essential war supplies, such as ammunition, fuel, and other supplies, are all wheeled vehicles. These vehicles are often heavy and large, falling into the category of oversized/special vehicles. Because of this, they slow down the traffic flow. The Croatian Army armed forces carry out convoy transport by different vehicles: defenders, HVs such as 5-tonne and 10-tonne trucks, and special vehicles such as flatbed trailers. Factors influencing average travelling speed (ATS) are the field conditions and the tactical-technological and dynamic characteristics of the vehicles. According to [5] and [6], road grade variation can significantly reduce vehicle speed as grades constrain the vehicle's acceleration and deceleration performance. This is especially true for heavy vehicles (HVs), as the ATS is negatively correlated with the percentage of such vehicles in traffic flow [7].

GIS is both time-efficient and cost-efficient tool for determining the optimal path according to terrain and vehicle parameters, in comparison to traditional military reconnaissance procedures, such as field surveys. By integrating a digital elevation model and road network, GIS calculates road grades, slopes, and variations that influence ATS. There is also a possibility to add data about different vehicles, depending on their characteristics, as attribute data in GIS. Various restrictions can be applied depending on whether the vehicle is wheeled or tracked. Key limitations also include the vehicle's dimensions and weight.

2.2 Mapping terrain passability

When moving armed forces as part of combat operations, it is important to assess the cross-country mobility of military vehicles. Determining the cross-country passability provides insight into the limitations of vehicle mobility and the creation of assumptions on the possible directions of movement of one's own and opposing forces [7]. GIS enables detailed mobility analyses for a range of vehicles, including those with and without tracks, based on a synthesis of geomorphological, geological, hydrological, soil, and vegetation data [3, 8], thereby determining areas deemed feasible, those with severe restriction, and those with impassability. These parameters are organized and displayed on passability maps (figure 2), which often have clear labels of observed areas by assigning them "GO", "SLOW GO", "NO GO" status, all of which can be utilized in route planning schemes and in mission graphic displays [3, 8]. These data can be used alongside that relating to road and track networks, crossings, and obstacles to enhance mobility by anticipating difficulties in the plans that have been made.

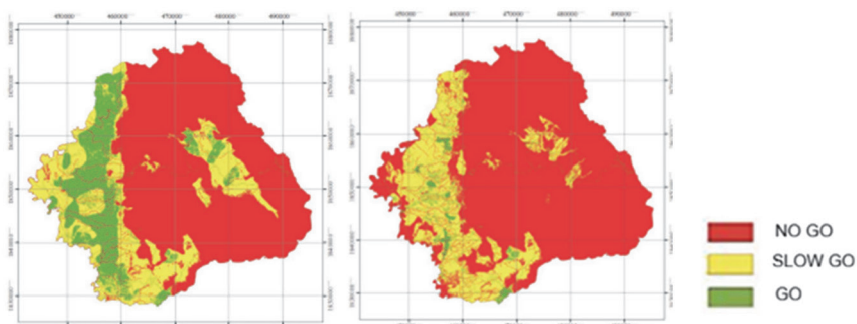


Figure 2 Example of a passability map containing "GO", "SLOW GO", "NO GO" areas for dry (left) and wet (right) conditions [8]

2.3 Software for route planning

Modern GIS platforms provide a suite of analytical tools to transform spatial and attribute data into actionable information for road network analysis. Core functions include: network analysis modules for determining optimal routes; slope and terrain ruggedness calculations; line-of-sight and radio-coverage modelling; and multi-criteria evaluation tools for route selection and risk assessment [2, 3, 9]. Within military route planning, software such as ArcGIS (including Network Analyst and specialized military extensions), QGIS, and Global Mapper support route optimization, coordinate management, distance and time calculations, and the creation of standardized grid reference graphics, with open-source solutions offering advantages where licensing or deployment constraints exist [2, 3, 9].

Commercial GIS software provides several route-planning modules capable of computing least-cost paths. Examples include PATHDISTANCE in ArcGIS, VARCOST and PATHWAY in IDRISI, as well as utilities within ArcGIS such as Network Analyst and Utility Network Analyst, which allow the assignment of weights to road segments and the imposition of traffic prohibitions or one-way restrictions [2, 3, 9]. When combined with real-time or near real-time data, these tools enable dynamic route adjustments that reflect current traffic or threat conditions [9-11].

3 Route planning methodologies

Vehicle route planning using GIS has a few advantages compared to traditional map-based techniques. It is less time-consuming than the manual map inspection, and it does not require on-site inspection of road conditions. Furthermore, information crucial for different situations can easily be incorporated into GIS. For example, during wartime, there is a need to consider the enemy's movement and activities as well. While planning friendly movement, the enemy's troop placement and the possibility of different obstacles, like minefields and barricades on the road, need to be considered. Additionally, during peacetime, the main military task is training, and military exercises demand movement from the area of deployment to the military training ground and resupply. In this chapter, the following route planning methodologies are presented: Dijkstra's algorithm, A*, Cost-surface analysis, and the Analytic Minimum Impedance Surface (AMIS) methodology. Dijkstra's and A* are commonly used for finding the shortest path, while Cost-surface analysis and AMIS are the best tools for creating passability maps.

Dijkstra's algorithm remains the classical method for computing shortest paths in networks with non-negative edge weights and is widely used in GIS-based routing applications [3, 11]. Conceptually, the algorithm iteratively expands a set of nodes whose shortest-path distance from the source is known, updating tentative distances to neighboring nodes until the entire relevant subnetwork has been explored. In raster-based GIS, each cell center may be treated as a node, with cell-to-cell transitions representing possible moves across the terrain [3]. Because standard Dijkstra implementations can become computationally intensive for very large or high-resolution networks, numerous variants have been developed. A* augments Dijkstra's method with heuristic estimates of remaining distance to the goal, thereby reducing the number of nodes that must be explored [3, 12].

Cost-surface analysis is frequently used to derive least-impedance routes across continuous terrain. In this framework, each raster cell receives a cost value that reflects movement difficulty arising from slope, land cover, soil conditions, hydrology, or tactical risk factors such as visibility and ambush potential [3, 9, 10]. Least-cost path algorithms then identify the route of minimum accumulated cost between specified origin and destination points. AMIS methodology is an example of an advanced GIS-based approach for corridor selection in complex environments [12].

AMIS aggregates a large number of spatial data layers, including environmental constraints, man-made obstacles, terrain metrics, and socio-economic indicators, into a continuous impedance surface, with weights derived from the Analytic Hierarchy Process [12]. AMIS supports the identification of highway or corridor alternatives that balance economic benefits against environmental and community impacts, while still providing the least-cost routing in the GIS environment [12]. Case studies analyzed during the literature review describe the use of digital elevation models and passability layers to simulate vehicle movement in mountainous terrain, the integration of real-time weather and road conditions to reroute convoys, and the application of GIS-based models to support rapid deployment in unfamiliar operational environments [3, 11]. Knowledge-based systems developed for combat operation planning can process data from remote sensors and GIS-derived products, utilizing acquired knowledge to assist in decision-making processes. They enable military commanders to create combat plans for the following four activities [10]:

- Selection of water obstacle crossing sites by using launching or pontoon bridges, enabling ground forces to cross water barriers.
- Selection of helipad locations depending on vegetation, soil conditions, and terrain slope.
- Identification of tactically important routes, i.e. roads and tracks leading to key terrain.
- Preparation of vehicle passability maps. Military vehicles are classified into two broad categories: tracked and wheeled vehicles. Vehicles like tanks exhibit excellent cross-country mobility; however, wheeled vehicles require careful route planning.

In addition to the aforementioned activities, GIS is also used for planning locations for defensive military industry facilities and assessing vegetation damage caused by tracked military vehicles.

4 Discussion

GIS technologies provide transformative capabilities for military vehicle route planning by integrating multi-source geospatial data, advanced analytical tools, and real-time modeling. Continued advances in data acquisition, algorithm development, and user training, along with robust interoperability and data-management frameworks, will further strengthen the role of GIS in military logistics, operational planning, and decision-making support in increasingly complex security environments [1, 11]. GIS technology is used for optimizing military vehicle route planning, integration of diverse geospatial data and advanced analytical tools for precise battlefield mapping, modelling, and visualization. Key findings demonstrate that accurate input data (terrain, transportation infrastructure, weather conditions, vehicle-dynamic characteristics) are prerequisites for quality spatial analysis, while a digital terrain model enables assessment of off-road movement beyond roadway edges. The characteristics of wheeled and tracked vehicles, along with their dimensions and weight, are particularly significant as they impact traffic flow.

The possible GIS application for military route planning is shown in table 1. It is a systematic review of all layers needed to be prepared for optimal route planning. After preparing a digital terrain model, depending on the type of vehicle, expectations and restrictions, a proper route planning algorithm needs to be applied. For finding the best route for a logistic vehicle Dijkstra's or A* is the most useful algorithm. To transfer ammunition, supplies or fuel from one specific point to another along the existing road infrastructure, the most important thing is to find the shortest path. AMIS is a more complex algorithm where the selection of corridors based on user-defined path inputs or endpoint location specifications is possible. This algorithm is useful for different corridors' evaluation and selection, depending on vehicle characteristics. Cost-surface analysis can be applied for tactical vehicles, risk assessment of terrain obstacles or the enemy's ambushes during their movement is very important.

Table 1 Possible methodology for GIS Military route planning

Input data	Topographic maps, geological maps, remote sensing data, field data
Thematic data preparation	Digital elevation model, landuse, landcover, lithology, hydrography, road infrastructure limitations, tacti-cal and technical data of vehicles
Route planning calculation	Mission area, distance, gradient, vehicle limitations, weather conditions, enemy forces
Route planning algorithm	Dijkstra's, A*, AMIS, cost-surface analysis

5 Conclusion

Despite their advantages, GIS-based route-planning systems face several important limitations. The reliability of analysis is heavily dependent on the availability of up-to-date, high-resolution spatial data; incomplete, outdated, or inconsistent datasets can lead to sub-optimal route choices and operational delays [1-3]. In many areas of interest, particularly in conflict or remote zones, comprehensive data acquisition remains technically difficult and resource-intensive. Software accessibility and interoperability also pose challenges. While proprietary systems offer powerful capabilities and established workflows, licensing costs and infrastructure requirements may restrict their deployment, especially for smaller forces or in austere environments [2, 9, 10]. Open-source platforms such as QGIS help bridge this gap, but ensuring interoperability among different systems and data formats, often across coalition partners, requires careful standardization and governance. Finally, effective exploitation of GIS demands skilled personnel with both technical and operational expertise; insufficient training or understaffed geospatial cells can limit the practical impact of even the most sophisticated tools [2, 3].

Future research should focus on systematizing data on military vehicles and transportation infrastructure to enable GIS to generate optimal movement routes. With the continuous development of GIS technology and the increasing availability of spatial data, further enhancement of military capabilities for effective space and resource management is expected. GIS will remain an indispensable tool for strategic decision-making in complex security environments.

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