GIS-BASED ANALYSIS OF EXCAVATIONS AS MOBILITY OBSTACLES IN MILITARY ENGINEERING

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Abstract
In areas affected by military operations, terrain plays a significant role in limiting vehicle mobility and maneuverability. Both natural and man-made obstacles, particularly excavations such as anti-tank ditches, are commonly employed as defensive measures to restrict enemy movement. The ability of vehicles to overcome these obstacles depends on their tactical and technical parameters as well as on terrain characteristics. The use of detailed terrain data and Geographic Information System (GIS) tools enables efficient identification of such obstacles and assessment of their passability. The proposed GIS-based model applies raster algebra and compares vehicle geometric parameters with terrain properties to evaluate cross-country mobility. This study provides a theoretical explanation of the role of terrain obstacles within Counter-mobility tasks and presents a methodological approach for their identification and assessment. A practical example demonstrates the evaluation of a potential man-made terrain obstacle and highlights the applicability of the proposed approach.

Keywords: *vehicle mobility, terrain passability, excavation, geospatial analysis, military engineering*

INTRODUCTION

Past and contemporary military operations have shown and continue to demonstrate that terrain is not merely the backdrop of a conflict, but an active, influential, and often decisive factor shaping vehicle movement and the actions of military units (Roskin, 2020). A thorough understanding of unit maneuverability is therefore a prerequisite for successfully accomplishing assigned tasks. For this reason, various assessments of terrain influence on the mobility of military vehicles have been compiled by military geographers for several decades (Heštera & Pahernik, 2018). Whether natural or constructed, terrain features can enhance or restrict the movement of forces thus hold significant tactical value (Abiodun & Fasaanu, 2025). Among the most impactful of these features are man-made obstacles, particularly excavations such as anti-tank ditches, designed to disrupt, fix, block or turn the adversary (Rolenec et al., 2024). Understanding how vehicles

interact with such obstacles requires not only knowledge of their technical capabilities, but also a precise characterization of the surrounding terrain.

An advancements in Geographic Information Systems (GIS) and the availability of high-resolution terrain data have opened new possibilities for evaluating cross-country mobility in operational planning (Rehrer et al., 2022). These tools enable the systematic detection of potential obstacles and the assessment of a vehicle's ability to overcome them, bridging the gap between theoretical mobility models and real-world terrain conditions. In mobility analysis, particular attention is given to the effects of slope and microrelief features (Dawid & Pokonieczny, 2021). While the influence of slope can be readily modelled using standard GIS tools, the evaluation of microrelief elements remains considerably more complex. Nevertheless, the technical parameters required to model a vehicle's ability to negotiate specific terrain obstacles are well established for each vehicle type. By integrating these vehicle-specific geometric parameters with detailed terrain analysis, GIS allows to identify areas where movement may be hindered and to anticipate the tactical consequences of both natural and man-made obstacles.

This article explores the role of terrain obstacles within the broader framework of Counter-mobility tasks and introduces a GIS-based methodology for their identification and assessment. Through a theoretical overview and a practical case study, it demonstrates how terrain analytics can enhance mobility assessments and support more informed decision-making in complex operational environments.

Vehicle Mobility and Obstacle Negotiation

Modern methods of conducting combat operations increasingly rely on detailed analyses of the operational environment using GIS tools (Marit, 2023). Such analyses are rarely performed in isolation; instead, they are approached comprehensively, drawing on GIS data of various types and levels of detail, accuracy, currency, and spatial coverage (Oleksenko & Mirzoyan, 2024).

A central component of military-geography assessment is the terrain mobility analysis (Cvijanović et al., 2018). Terrain mobility can be defined as the degree to which specific vehicles are technically capable of moving through the landscape and overcoming natural or man-made obstacles (Bradbury et al., 2018). A qualified assessment of terrain mobility requires the examination of individual geographic features and landscape phenomena, combined with the technical parameters of military vehicles, relevant tactical factors, and human considerations.

When evaluating the geographic conditions that influence mobility, particular attention is devoted to factors such as terrain slope of the terrain, microrelief, vegetation cover, soil conditions, climate characteristics, hydrological features, settlement patterns, and transportation networks (Hubáček et al., 2016a). Each of these factors has been extensively examined in numerous previous studies, which have explored their individual influence on vehicle movement and obstacle negotiation in detail (Hubáček et al., 2015; Talhofer et al., 2015; Bekesiene et al., 2019; Kristalova, 2024; Dawid & Pokonieczny, 2025). These research efforts collectively provide a solid analytical foundation for understanding how environmental conditions shape the mobility of military vehicles in various operational settings.

In general, microrelief features can be understood as terrain elements whose elevation differs from the surrounding landscape by no more than a few meters. These features typically occur as linear or point-like landforms, commonly represented by gullies, erosion channels, terraces, excavations, embankments, pits, and similar structures. Although small in scale, microrelief elements can significantly influence movement across the terrain.

From a mobility perspective, the shape, size, orientation, and spatial configuration of microrelief features affect the maneuvring options of both individual military vehicles and entire units. Depending on their characteristics, such features may constrain movement, force detours, create potential choke points, or alternatively offer concealment and covered approach routes. Numerous studies have examined these factors individually, demonstrating that even subtle microrelief variations can meaningfully alter tactical mobility in complex terrain (Hubáček et al., 2016b; Dawid et al., 2024; Sedláček & Dohnal, 2024; Potić & Đorđević, 2025).

Microrelief obstacles can generally be overcome in two distinct ways. The first involves the direct negotiation of the obstacle by the vehicle itself, while the second consists of bypassing the obstacle (Hubáček et al., 2016a). Both approaches inevitably lead to a reduction in the speed of advance; in the case of bypassing, they also require additional maneuvring, which can further disrupt movement and potentially expose units to tactical risks.

Counter-mobility Tasks – Definition and Purpose

Operations (with Counter-mobility tasks) are a component of the protection and movement and maneuver warfighting functions, aiming to deny the enemy the use of key terrain and mobility corridors. Counter-mobility tasks include obstacle

construction and route (area) denial. An obstacle is defined as a natural or man-made object that creates a physical impediment to, or hazard to, the movement of vehicles. Within this framework, geospatial and combat engineers utilize terrain analysis to categorize the landscape into GO, SLOW GO and NO GO terrain, allowing commanders to identify where counter-mobility tasks can most effectively disrupt the enemy's synchronization and force them to abandon their planned tempo (Rolenec et al., 2021).

The primary purpose of counter-mobility tasks is to shape the battlefield to favor the defender's scheme of maneuver while maximizing the effectiveness of friendly weapon systems. By constructing reinforcing obstacles, such as anti-tank ditches and walls, or enhancing existing natural features like rivers, forests, and steep slopes, forces can effectively "canalize" the enemy into pre-determined engagement areas covered by direct and indirect fire. In addition, counter-mobility measures are designed to protect the most vulnerable elements of a combat formation, including flanks, command posts, and logistical nodes. The effectiveness of these tasks does not lie in an obstacle's ability to be a permanent barrier, but in its ability to buy time and expose the enemy to observation and fire during the breaching process. Successful execution requires the seamless integration of geospatial intelligence, engineering earth-moving capabilities, and tactical planning to ensure that obstacles are not easily bypassed, but instead serve as force multipliers for the defense (Rolenec et al., 2024).

Terrain Obstacles in Counter-mobility Operations

Counter-mobility operations rely on the tactical integration of terrain obstacles to shape the battlefield and degrade the adversary's freedom of maneuver (see Figure 1 – left). Tactical obstacles are primarily intended to disrupt, turn, fix, or block enemy forces into vulnerable positions where they can be effectively destroyed. These obstacles are categorized into existing features, such as natural rivers or steep slopes, and reinforcing obstacles that are deliberately constructed or emplaced by military engineers (AOL News, 2025).

Non-explosive obstacles represent a critical subset of these measures, offering a sustainable and durable means of terrain denial (see Figure 1 – right). To fulfill their tactical purpose, these obstacles must be difficult to overcome, resistant to rapid removal, and carefully integrated into a broader defensive system. No physical obstacle is a "force field"; their effectiveness is fundamentally dependent on being under constant observation and covered by direct or indirect fire (AOL News, 2025).

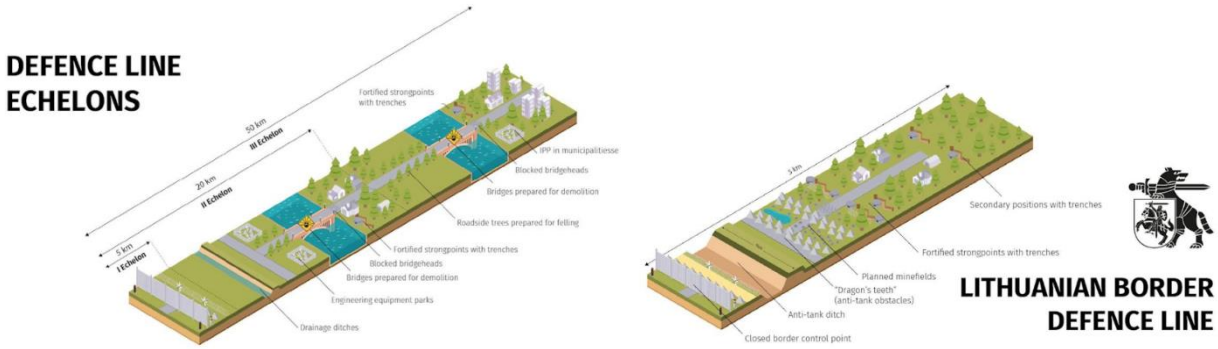


Figure 1. The 30-mile border defenses include ditches and bridges that are prepared for demolition (left) and the first three miles of the new defenses include anti-tank measures (right) (AOL News, 2025).

Within the category of non-explosive earthworks, anti-tank (AT) and anti-vehicle (AV) ditches serve as primary tools for halting armored and motorized advances. AT ditches are large-scale, field-engineered obstacles, typically featuring a trapezoidal cross-section with a depth of approximately 2.5 meters and a top width of 5 to 5.5 meters (see Figure 2). These dimensions are specifically designed to immobilize main battle tanks (MBT), forcing the enemy to either attempt a costly bypass or expose specialized breaching equipment to defensive fire.

In contrast, AV or traffic ditches are specialized obstacles often emplaced along or across lines of communication to impede wheeled and light tracked platforms. These generally feature rectangular or triangular profiles with a more modest depth of approximately 1 meter. Although AT ditches provide depth to a primary defensive line, AV ditches are often used as supplementary measures to frustrate the enemy's logistic momentum. All of obstacles and their effectiveness are influenced by proper siting, camouflage, and the use of local materials.

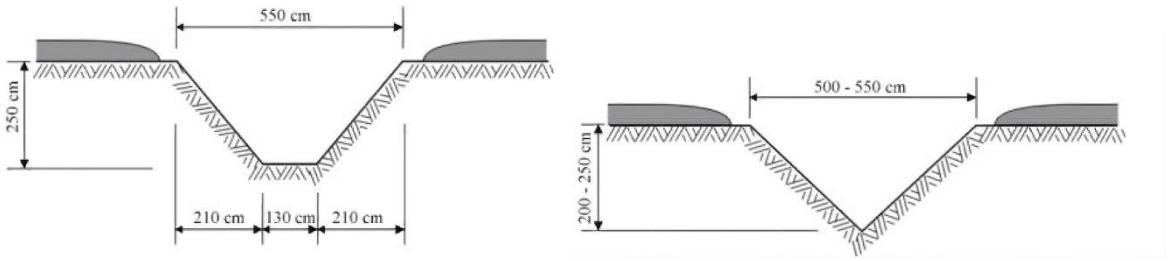


Figure 2. Dimensions of anti-tank ditches.

The AT and AV ditches are components of non-explosive obstacles designed to stop or delay an adversary's advance, break their combat formation and transform them into designated engagement areas (see Figure 3). As field-engineered "reinforcing obstacles", they are categorized as NO GO terrain for most ground maneuver units.

The effectiveness of a ditch is determined by the crossing capability of the target vehicle (Pimpa et al., 2014):

- tracked vehicles (tanks): to stop modern MBTs, ditch dimensions must exceed the vehicle's inherent crossing limits; even if not insurmountable, the ditch forces a reduction in speed, leaving the tank vulnerable to defensive fire.
- Wheeled and light tracked vehicles: these platforms are sensitive to ditches due to higher ground pressure and limited ability to overcome steep vertical walls; even shallow AV ditches can achieve total immobilization.
- Soil and weather conditions: the obstacle's impact is magnified by soft or saturated soils (e.g., clay or mud), which lower the Rating Cone Index (RCI), reducing traction, and making self-recovery nearly impossible (Marková et al., 2025).

Ultimately, these obstacles only remain effective if they are observed and covered by fire; otherwise, enemy combat engineers can rapidly overcome them using armored vehicle-launched bridges (AVLB) or dozers (Rolenec et al., 2021).



Figure 3. Example of anti-tank ditch from the war Ukraine vs. Russia (supplemented with concertina wire) (GermanDronePilot, 2026).

When assessing options to overcome these obstacles, it is essential to evaluate the geometric characteristics of the constructed feature, such as width, depth, slope angles, and profile shape in relation to the mobility parameters of the vehicle trying to negotiate them. Critical factors include the ground clearance of a track vehicle, the track length, the approach and departure angles, and the maximum trench-crossing capacity. A mismatch between obstacle geometry and vehicle parameters can render direct crossing impossible, requiring detours, specialized engineering support, or the use of bridges and gap-crossing assets.

METHODOLOGY

Therefore, an accurate assessment of the ability of a vehicle to traverse microrelief obstacles requires detailed knowledge of the tactical-technical parameters of the military platform, such as ground clearance, approach and departure angles,

maximum climbing capability, and mobility performance, as well as reliable information on the dimensions and shapes of the microrelief features present in the terrain (Dohnal, 2020). With these data, it becomes possible to determine whether specific obstacles can be directly negotiated or whether a bypass is necessary, ultimately shaping route selection, movement planning, and overall operational mobility.

The proposed methodology for assessing the influence of the size and shape of microrelief obstacles is based on the limiting capabilities of tracked vehicles to negotiate microrelief features and on determining whether a given terrain location is passable by a selected vehicle. It was necessary to define a set of input assumptions, namely that microrelief features are represented by concave depressions comprising a bottom and two banks, that their profile characteristics do not undergo significant temporal changes and can therefore be interpreted from a digital elevation model (DEM), that the physical (mechanical and dynamic) properties of the banks and bottom are neglected, that vehicle technical parameters are considered constant, and that neither suspension nor terrain deformation under vehicle loading are taken into account.

The stated input assumptions led to the definition of conditions for the development of a mathematical model to assess the influence of microrelief features on their negotiability, from which a geoinformation model was subsequently derived.

Mathematical Model for Obstacle Assessment

The analysis is based on the evaluation of the influence of the front approach angle α_a of a tracked vehicle on the negotiation of microrelief obstacles. The mathematical model focuses on identifying microrelief features for which the situation illustrated in Figure 4 may occur, in which the vehicle impacts the opposite bank of the obstacle in the direction of movement.

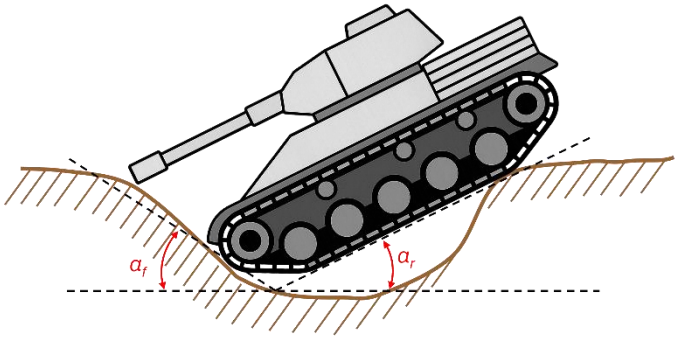


Figure 4. Schematic representation of a tracked vehicle immobilised in a ditch (α_f – front angle α_r – rear angle).

If condition (Equation 1) is satisfied, a frontal collision between the vehicle and the obstacle bank does not occur, and consequently the vehicle does not become immobilized within the microrelief obstacle.

$$\alpha_f + \alpha_r < \alpha_a \,, \tag{1}$$

where α_f is the front angle, α_r is the rear angle of a modeled vehicle, and α_a is the front approach angle.

GIS-Based Model for Obstacle Assessment

The geoinformation model was developed using the Python scripting language. The model takes two data components as input:

- Very-high resolution DEM in TIN format.
- Front length (overhang) l_f (longitudinal distance from the front of the vehicle to the first driving wheel) and rear length l_r (longitudinal distance of the vehicle's center of gravity from the first driving wheel).

The main objective is to use the map algebra to identify pixels whose value represents the sum of the modeled values α_f and α_r and exceeds the value of α_a for the vehicle under analysis. The computation accounts for the eight principal directions of vehicle movement in terrain: north–south (N–S) and vice versa, northeast–southwest (NE–SW) and vice versa, east–west (E–W) and vice versa, and southeast–northwest (SE–NW) and vice versa. The calculation is performed in several steps in which a mathematical model is applied:

1. Definition of the raster pixel size (0.3, 0.4, or 0.5 m) with respect to the input parameters (optimization of the mathematical model within the geoinformation model).
2. The α_f and α_r values are computed using the Focal Statistics tool (calculation following the assumed vehicle trajectory, pixel by pixel). In cases where the computation is performed on rasters with differing pixel resolutions, the outputs are subsequently reclassified to a raster with a 0.5 m pixel size.
3. The sum of the α_f and α_r values is calculated with respect to the eight principal directions of movement, based on slope orientation analysis.
4. Pixel's values classification (GO if the condition in Equation 1 is satisfied; otherwise, NO GO).

Case study

The applicability of the model was evaluated in a military training area featuring men-made obstacles constructed for testing purposes, with a particular emphasis placed on an AT ditch as the primary area of interest. As a input DEM was used model from high-precision LiDAR scanning in the military training area using the DJI Matrice 300 RTK UAV equipped with the DJI Zenmuse L1 LiDAR system (ranging accuracy RMS (1σ) of 3 cm at a nominal flight altitude of 100 m) (DJI, 2026). The Zenmuse L1 integrates a Livox Avia laser scanner, an inertial measurement unit, and an RGB camera, enabling the simultaneous capture of dense point clouds and colorized imagery for detailed spatial analysis (see Figure 5 – left).

The analysis was performed for selected tracked vehicles (tanks Leopard 2A4, Leopard 2A7, T-72, and infantry fighting vehicle BVP-2) using the parameters presented in Table 1. Given that the AT ditch is oriented along the S–N direction, only this direction was considered in the model (see Figure 5 – right). The longitudinal profile of the ditch is presented in Figure 6. The main objective of the study is to validate the applicability of the model through a case study of a constructed AT ditch and to confirm the assumption that a ditch intended to prevent tank and vehicle movement will be classified as a NO GO area by the model.



Figure 5. Colorized point cloud of the testing area (left) and visualization of the anti-tank ditch derived from the generated DEM (TIN format), including the modeled vehicle movement direction oriented S–N (red arrow) (right).

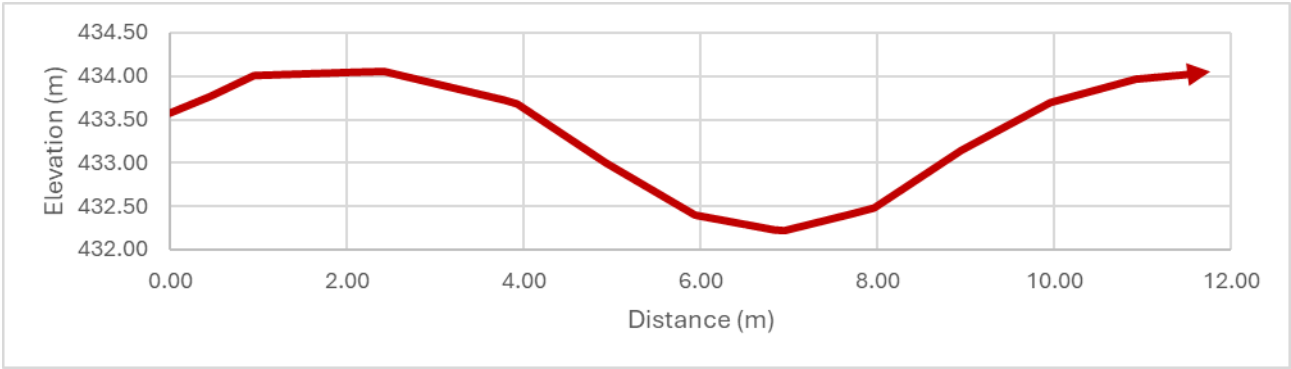


Figure 6. Longitudinal profile of the AT ditch.

Table 1. List of tracked vehicles and their parameters

Tracked Vehicle	Approach Angle α_a	Front Length l_f	Rear Lengtt l_r
Leopard 2A4	30°	1.34 m	2.92 m
Leopard 2A7	35°	1.34 m	3.03 m
T-72	30°	1.38 m	2.43 m
BVP-2	35°	1.64 m	1.93 m

RESULTS

The individual model outputs for each selected vehicle and their visual representations are shown in Figure 7. The model produces a raster with a pixel resolution of 0.5 × 0.5 m, where the pixel values represent the sum of the modeled α_f and α_r values. The red pixels indicate locations where a frontal collision between the vehicle and the opposite bank of the ditch would occur, which is consistent with the initial hypothesis that the analyzed ditch is impassable for the selected tracked vehicles. In these areas, the pixel values did not satisfy the condition defined in Equation 1.

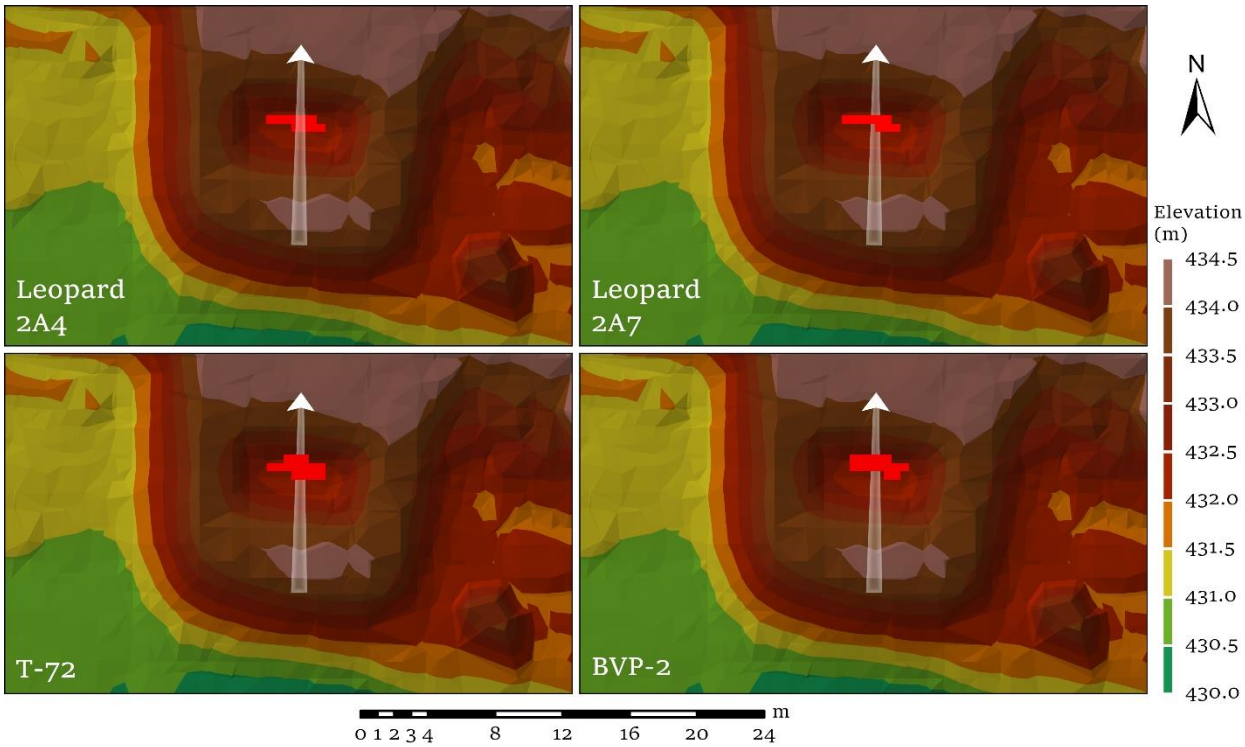


Figure 7. Model outputs for individual vehicles (the white arrow represents a vehicle movement).

In general, it can be concluded that the presented results reflect the fact that the location of the frontal collision in the specified direction shows almost no variation among the selected vehicles. Considering the stated input assumptions and the limitations of the model, the model predicts the location of a frontal impact of the vehicle with the opposite wall of the ditch for all selected vehicles.

DISCUSSION

The study shows that high-resolution terrain data combined with a GIS-based framework offer a robust, physically interpretable tool for assessing how man-made excavations affect the cross-country mobility of military vehicles. By directly linking vehicle geometry to detailed microrelief, the method enables transparent, reproducible evaluation of obstacle passability from geometric constraints. An AT ditch case study confirms that the model aligns with doctrinal expectations, classifying the obstacle as NO GO for all analyzed tracked platforms, while providing clearer insight for engineers and planners than generalized mobility indices or empirically weighted cost-surface methods.

From an engineering and defensive design perspective, the results highlight the potential of GIS analytics not only for mobility assessment but also for obstacle planning and optimization. The model may enable reverse reasoning, whereby the known technical parameters of adversary vehicles can be used to define minimum geometric requirements for

excavations or AT ditches to ensure their tactical effectiveness. In this regard, the methodology supports both mobility and counter-mobility tasks, bridging analytical terrain assessment with practical field engineering decisions.

However, several limitations of the model must be acknowledged. The analysis is based on a set of simplifying assumptions, most notably the neglect of the mechanical properties of the soil, the suspension behaviour of the vehicle, the deformation of the terrain under load, as well as the adhesion characteristics of the terrain surface. In real operational conditions, variations in soil moisture can significantly affect adhesion coefficients and rolling resistance, thus altering vehicle traction forces. These factors can substantially influence obstacle negotiability, particularly in soft or saturated soils. Furthermore, the model does not include all variants of longitudinal and transverse slopes and spatial extent of terrain relief segments, evaluates static geometric conditions, and does not account for dynamic effects such as vehicle speed, momentum, or driver behaviour, which may allow marginal obstacles to be crossed under favourable conditions. An additional source of uncertainty arises from the determination of the vehicle's centre of gravity and the definition of its geometric lengths for the front (l_f) and rear (l_r), which are not always explicitly available and can vary depending on vehicle configuration and load state. For this reason, the position of the vehicle's centre of gravity was determined based on expert estimation derived from available technical documentation and engineering judgement. Nevertheless, this model can serve as a basic mobility platform for other models and their verification through field tests.

Data quality also plays a critical role in the accuracy of the model. Although UAV-based LiDAR provides exceptionally detailed terrain information, the proposed method is not limited to such data and remains applicable when using lower-resolution digital elevation models or alternative data sources. The methodology was verified through field testing using military wheeled vehicles, and the results demonstrated that a national-level elevation dataset, specifically the Digital Terrain Model of the Czech Republic of the 5th generation, provides sufficient accuracy for reliable modelling of terrain obstacles. These findings indicate that widely available national DEMs can be effectively used for practical mobility and counter-mobility analyses, thereby increasing the operational applicability of the proposed approach beyond data-rich environments.

Future research should integrate additional terrain factors, such as soil strength and moisture, and develop dynamic or probabilistic formulations of obstacle negotiation to improve the realism of mobility assessments. At the same time, the proposed GIS-based model already enables the definition of geometric and dimensional requirements for terrain obstacles based on the capabilities of specific adversary vehicle fleets, supporting both mobility planning and counter-mobility engineering. By linking obstacle construction with vehicle performance, the approach provides a valuable analytical framework for the systematic design and assessment of excavations or AT ditches, even in its current form.

CONCLUSION

This study has presented a methodology based on GIS - to assess excavations as mobility obstacles, with a particular focus on anti-tank ditches in the context of military counter-mobility operations. By combining high-resolution digital elevation data with vehicle-specific geometric parameters, the approach enables an objective classification of the terrain as GO or NO GO based on physical --based constraints on obstacle negotiation. The key contribution of the presented work lies in its explicit integration of vehicle geometry and terrain microrelief into a unified analytical framework. Mathematical and geoinformation models allow for spatially explicit identification of locations where vehicles are likely to become immobilized due to frontal impact with obstacle banks. The practical case study confirms that the method provides results consistent with the doctrinal expectations and highlights its applicability to real-world engineered obstacles.

The results underline the broader significance of GIS as a decision-support tool in military engineering. When supported by accurate terrain data, GIS enables not only retrospective analysis but also proactive planning of both mobility and counter-mobility measures. The proposed approach can support commanders and engineers in route selection, obstacle siting, and defensive design by providing clear, reproducible, and visually interpretable outputs.

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BIOGRAPHY



Filip Dohnal graduated from the University of Defence in Brno in 2015 with a degree in Military Geography and Meteorology. He completed his Ph.D. studies at the same university in 2020, focusing on GIS-based modeling. He gained professional experience as a surveyor and GIS database administrator in private companies. Since 2020, he has been working as an Assistant Professor at the Department of Military Geography and Meteorology, University of Defence in Brno. His research focuses on cartography, data visualization, spatial terrain analysis, and data acquisition for crisis management, public protection, and military purposes. He currently focuses primarily on terrain passability modeling and aims to broaden the application of GIS across various military branches, particularly in engineering, logistics, and artillery.



Major Radek Procházka, graduated from the Military Academy in Brno (2003). He completed his studies in the Military Structures degree program, specializing in the Mechanization of Special Construction. Between 2003 and 2024, he held various positions at the Training Command – Military Academy in Vyškov, with his final appointment being the Head of the Engineer Training Section. In 2011, he completed the Senior Officers Course in State Defence and Management at the University of Defence in Brno. He currently holds the position of Assistant Professor within the Engineer Support Management Group of the Department of Engineer Support, Faculty of Military Leadership at the University of Defence in Brno.



Professor Marian Rybanský, graduated at Military Academy in Brno in the field of geodesy and cartography in 1982. Senior editor (1982-84) and the head of the automated map production department (1984-86) at the Military Geographical Institute in Prague. Head of the cartography group at the Department of Military Information on the Territory, MA Brno (1994-2005). In 1996. Internship at CFB Borden, Ontario, Canada (1996). Professor of geodesy and cartography at the University of Defence in 2021. Main research area: analyses of the landscape in terms of its impact on the mobility and navigation of military vehicles. Main researcher, resp. co-investigator of 28 national and 10 international projects. Author or co-author of more than 200 publications including 4 books and 10 methodologies and 2 patents for industry.



Professor Václav Talhofer, graduated from the Military Academy in Brno in 1978 with a specialisation in geodesy and cartography. He was employed at the Military Topographic Institute as a topographer and computer programmer (1978–1980) and subsequently held an academic appointment as a university lecturer (1980–1993). He later served as Editor-in-Chief of the Geographic Service at the General Staff of the Army of the Czech Republic (1994–1995) and as Head of the Department of Military Geography and Meteorology at the University of Defence in Brno (1996–2011), and he continues to teach at university level. In 2017, he was appointed Professor of Geodesy and Cartography at the Czech Technical University in Prague. His research focuses on cartography and landscape analysis, particularly their implications for the mobility and navigation of military vehicles, and he has contributed to 12 national and five international projects and authored or co-authored more than 190 publications, including four books.