Utilizing the Maneuver Control System CZ in the Course of Wargaming Modelling and Simulation

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Abstract. This article describes the use of mathematical algorithm models and digital terrain and relief models in the process of planning the maneuver axes of military units and military vehicles using the Maneuver Control System CZ. The maneuver axes of units on the battlefield are calculated based on the impact of the surface and terrain relief, the weather, and on the influence of the deployment of the enemy and friendly units. Calculated maneuver axes may be applied to analyze the variants of action both of friendly and the enemy's military forces, which may be carried out in the form of a so-called war game as part of the Commander's decision-making process. For the needs of the war game, the MCS CZ can quickly calculate the possible maneuver of enemy units and can subsequently also calculate the reaction – the maneuver of friendly units, and finally the possible counter-reaction of the enemy. Research results of the war game, using MCS CZ calculations, are described in case study. This case study analyzed the activities that were the most likely and most dangerous variants of enemy action, as well as the possible reaction of friendly forces in engaging in defense. Calculations of the axes of maneuver and times were compared with the simulation in the software MASA SWORD. The calculated axes of maneuvers in both programs confirmed the tactical correctness of the deployment of the friendly combat security detachments.

Keywords: Terrain passability · Course of action · Decision-making process · Multiple maneuver model · Situation awareness

Gaining superiority over the enemy and meeting targets in a military operation is contingent on a quick understanding of the situation on the battlefield. In order to do this, pieces of information must be collected efficiently, analyzed quickly, and the evaluation results must be used in the performance of combat tasks. On such a basis, a qualified estimate of the enemy course of action (COA) can be compiled, followed by the timely and efficient deployment of friendly forces exactly where they are needed. No decision-making by commanders and staff can be haphazard. In NATO armies, at the tactical level of command and control, the so-called military decision-making process (MDMP) is used to give the decision-making process a logical structure, efficiency, and the ability

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to co-operate with all commanders and unit staffs in the operation. The MDMP is a cyclic planning methodology carried out to analyze and understand the situation and the task, to produce and contrast variants for friendly units' operations, and to issue an operational order to implement the selected COA of friendly forces [1, pp. 2–17].

A significant influence on the COA of friendly forces is one's estimation of the intention of the enemy, which is one of the most demanding parts of intelligence security in a military operation. It is affected by the considerable degree of uncertainty about the objects and targets of the enemy, and the associated means of achieving them successfully. An analysis of the situational factors, the enemy, and other threats needs to be carried out in order to make a qualified estimate of the position of these targets and the course of the main, secondary and supporting maneuver to implement them. In the event that the presumed enemy COA is dynamic, coupled with a unit maneuver in order to gain control over a particular area, then a key factor in the evaluation will be the overall passability of the area, with the least hazard risk. If the enemy's maneuvering is expected to achieve its targets as fast as possible, then the course of its COA can be estimated as the fastest passable and safe.

The war game, which is based on the outputs of the process of intelligence preparation of the battlefield (IPB), is applied in NATO armies to analyze and evaluate the COA of friendly forces, see [2, pp. 1–1, 3–1, 6–20]. One of them is an estimate of the enemy COA, assessed in terms of probability and hazard [2, pp. 1–4]. Based on a qualified estimate of the enemy COA, intelligence-gathering efforts can be more accurately targeted, as can preliminary measures be implemented to safeguard the activities of friendly forces, including avoiding an unexpected attack by the enemy. The result of the war game is then a simulation of a planned maneuver by friendly forces, along with the expected reaction of the enemy forces, supplemented by a counter-reaction by friendly forces. For all the considered COAs are assessed, e.g. the time of implementation, advantages and disadvantages, strengths and weaknesses, the element of surprise, combat effectiveness and the real ability to achieve the planned targets of friendly units as well as the anticipated targets of the enemy forces. The ability to coordinate the efforts of units on the battlefield is equally important. The war game is a structured process by which commanders and staff attempt to anticipate the development of an operation. It uses a method of action-reaction-counter reaction in assessing the development of each critical event in the considered COA, in the interaction of friendly forces and those of the enemy, which is applicable to all types of military operations [3, pp. B–21]. It can be performed manually, using graphically assessed terrain passability, military vehicles capability tables, and tactical activity models on a map. With this variant, assessing the tactical characteristics of the terrain and the environment, the threats, and the conduct of the war game can take – depending on the experience of the analysts, the scale and the predictability of the development of the operation – from 6–12 h. These days it is much more efficient to use digital land and relief models, mathematical algorithms, modelling, and computer simulations.

1 Literature Review

The MDMP is described in a number of US military publications, e.g. in [1, 3, 4]. Its use in dealing with crisis situations, with its problematic acquisition, understanding and use of information is further characterized, e.g. in [5]. The goal of the MDMP is always to resolve a situation as quickly and comprehensively as possible, or to plan the execution of a mandated task. The result can take the form of creating axes for maneuver of friendly units, which in combination with a high mobility for enemy units, can be time-consuming. Digital geographic data models and mathematical algorithms can be used to solve this problem in the 21st century digital battlefield environment.

The mathematical modelling of the maneuver axis is based on the information layers of the digital terrain and relief model, which are described in more detail in [6–8]. Creating these models takes considerable time. The automated assembly of digital models is currently performed using various sensors, algorithms and computer graphics, see [9–12]. Assessing the impact of soil, obstacles, microrelief and field cover on military vehicle mobility and decision-making is depicted in [13–15]. Modelling the combined impact of relief, microrelief, soils, vegetation, hydrology, built-up areas, and meteorological factors on the speed deceleration of off-road vehicles in the raster geographic data format is then specified in [16–18].

The maneuver of units in military operations is currently largely carried out by road, due to the limited passability of the wheeled fighting vehicles, the efficiency of redeployment at an acceptable risk, as well as efforts not to cause unnecessary damage to agricultural land. Various road passability parameters and assessments of maximum speed values that can be used during redeployment are evaluated in [19]. However, if the road network does not allow this, or the safety risk is disproportionately high, the maneuver must be taken through terrain off the roads. The issue of identifying the course of the shortest route between two points in a computerized environment of geographic information systems using algorithms is addressed in [20]. It is then possible to find the creation of axes for multiple maneuvers using different algorithms in [21]. Analyzing the COA of friendly units by applying software to conduct a war game during the MDMP is described in [22, 23]. In the current battlefield environment, there are likely to be large numbers of units, military vehicles, armed and criminal groups, as well as religious and non-profit organizations. Software using artificial intelligence (AI) and the expected activity of a large number of entities in the operating space can recommend improvements to the commander and staff in the course of action (COA) of friendly units. The possibilities of using AI in planning the axis of a war game maneuver in the computer environment can also be found in [24]. Research and experiments in using expert computer systems in the execution of war games to minimize prejudices and risks associated with decision making is described in [25–27]. The innovative contribution here is to use dynamic modelling and the simulation of new approaches in designing theoretical models of capability development that shape the core of expert systems. The purpose is to draw a qualitative comparison between the two proposed sets of capability requirements.

The Tactical Decision Support System (TDSS) was developed at the University of Defence of the Army of the Czech Republic in 2006, see [28]. The TDSS is designed to support the decision-making process of commanders and staffs at the tactical level of command and control, using mathematical models and raster representations of tactical-geographic data. Current military operations are typically conducted in a complex environment, where the activities of friendly units are influenced not just by the enemy, but also by the civilian environment, with lots of entities with different types of socio-cultural behavior. To conduct a war game in the complex environment of current military operations, it is advisable to use so-called multi-agent modelling, evaluated e.g. in [29].

The "optimal movement route model" was implemented in TDSS in 2015, see [30, 31], which combines the effects of situational factors in its calculations. The result of the mathematical algorithms is that the axis of the maneuver is optimized on the basis of predefined criteria for the maneuver's speed and safety. The method for rapidly forming the axes of the four fundamental tactical maneuvers of units is made possible by the Maneuver control system (MCS CZ), implemented in the TDSS in 2019, whose functionality is described in [32]. These are the maneuvers of frontal attack, envelopment, turning movement and attack by fire. The spatial expression of these maneuvers, then, provides guidance for the movement of units on the battlefield in order to take advantage of the enemy. Based on its structure, information inputs, mathematical algorithms and linkages, graphical outputs, time calculations and processing speed, the MCS CZ is suitable for use in war gaming.

2 Maneuver Control System CZ

The basis for calculating the MCS CZ maneuver axis – optimized in terms of time-constraints and safety – is the "optimal movement route model" created by the author, see [30]. The model combines the influences of different spheres of the battlefield through map algebra, mathematical linkages, and criterion assessment. Implemented in the TDSS, this model assesses the effects of surface and terrain relief, weather, enemy activity, and friendly forces on the battlefield, in the form of raster mathematical layers. The MCS CZ allows the calculation of maneuver axes of a group of elements coordinated with each other to achieve the same target. It can be used both to calculate the axes of maneuvers of friendly units as well as the supposed maneuvers of the enemy. The MCS CZ mathematical models of unit maneuvers and military vehicles use a raster format representing the digital land model data and a digital relief model from the space of operation.

The structure of the optimal movement route model as the basis for MCS CZ is made up of several matrix layers that represent individual groups of horizontal and vertical passability factors (motion intensity) of the space. These layers (factors) influence the choice of the axis of maneuver of units and military vehicles in terms of terrain passability and situation safety. Each raster cell contains a numerical value for the difficulty of surmounting it, derived from the current state of impacts of mission variables at a given position in space. These are represented by the horizontal factors of cost surface (CS1), weather (HF3), influence of enemy forces (HF4), supporting influence of friendly units (HF5) and the vertical challenge factor of the terrain relief maneuver (VF2), dependent on the criterion assessment of their occurrence characteristics, shown in Fig. 1 and described in [30, p. 557]. The criterion scoring metric varies for each layer, taking into account its character and composition. The basic data for calculating it are the cell dimensions, the average redeployment speed for the selected element on a given type of terrain surface that moves across the cell, and the magnitude of resistance of the factor under consideration.

The basis for the model calculations is CS1, characterizing the speed of maneuvers on individual surface types for the geographic conditions of Central Europe. The model generally considers larger bodies of water, such as ponds, dams or lakes impassable for conducting tactical maneuvers. They are surmountable for floating forces and resources, depending on their capabilities. Swamps and marshes are always rated impassable. The speed of maneuver on each type of surface may vary, depending on the technical characteristics of the vehicles, the experience of the operator and the readiness of the infantry units. The terrain elevation layer is formed by its relief, which enters the final combined cost surface (CCS) calculation with the vertical ground slope factor (VF2). Its definition can be defined as the degree of difficulty of moving on the terrain relief. In the layer weather (HF3) and its effects, only snow and rainfall are considered as blanket effects on ground passability, see [30, p. 559]. The enemy situation layer (HF4) assesses the passability of an area against the safety criteria for redeploying elements of friendly forces, depending on the deployment, armament, range and visibility of enemy units. The layer of the factor of influence of friendly military forces (HF5) expresses the degree of elimination of the influence of enemy activity, in the sense of support for surmounting (passability) the hazardous area of the task. It represents the space within the visibility and distance of conducting effective fire with friendly units not performing the calculated maneuver. The mathematical calculation of the combined influence of all the considered layers of influence factors on passability and speed of surmounting space is represented by the resulting matrix layer of CCS, see the equation below (1). The CCS calculation is based on the average repeatedly measured speed of a particular vehicle type on a specific ground surface. The result of this calculation is in the form of hundredths of a second. It is further modified by mathematical linkages and criteria evaluation of the influence of other situational factors such as terrain relief, weather, the enemy and the support of friendly forces. The value of the time of overcoming each matrix takes into account the combined influence of all factors of the situation, calculated using (1), which creates the CSS of the whole space. The shortest and safest path is then given by the sum of the matrix values with the smallest cumulative value. The CCS – as the result of the calculations of the model optimal axis of the maneuver – is then used to calculate the fastest safe axis of the maneuver in the TDSS using the modified Floyd-Warshall and Dijkstra's algorithm for finding the shortest route, see [33, 34].

$$CCS = \frac{CS_1}{VF_2 \cdot HF_3 \cdot \min(1, HF_4 \cdot HF_5)} \tag{1}$$

The MCS CZ offers calculations for 4 offensive maneuvers, i.e. frontal assault, attack by fire, envelopment and turning movement, as described in [32]. Frontal assault uses a search algorithm to find the shortest route on the basis of the CCS optimal movement route model. Its objective is the fastest safe axis of maneuver to the target object or enemy unit. The fire attack maneuver also uses a search algorithm for the shortest route on the base of the optimal axis CCS model. The axis target of its maneuver is not an object or position of an enemy unit, but the nearest edge of the visibility area to the target enemy at the distance of effective fire for the purpose of its firing destruction. The encirclement maneuver is based on the assumption of coordinated implementation with units acting frontally. To specify its course, it uses an invisible layer with a circular-shaped impassable space between the initial position of the friendly maneuver unit and that of the target enemy. Its radius is equal to the distance D, which is the distance between the two positions, no more than 1 km. This distance is adjustable and was chosen because of the average distance for the effective firing of units operating frontally and the time possibilities to surmount such a semicircular distance to the target. Specifications for the course of maneuver circumvention were also established on the assumption of its coordinated execution with units acting frontally. It is delineated by an invisible layer with an impassable space in the form of two heart-shaped semi-ellipsoids, formed on both sides between the starting point and the target point of the maneuver, at the distance D of no more than 1 km. The shape of the two semi-ellipsoids has the largest length equal to 1.3D and the largest width is 0.5D; see Fig. 1 – Maneuver models layer.

All four models of MCS CZ maneuvers can be used to calculate the so-called Group Unit Maneuver. A group maneuver is the collective maneuver of a set of units (companies, platoons, squads and smaller elements or a group of UGV) to act in a coordinated manner on the same target object. The individual axes of maneuvers are then calculated in a sequence, based on the subordination or organizational division of the individual elements, in three-person formations. Based on the size or type of tactical element (company, platoon, squad or UGV), it is then necessary to adjust the width of the restricted area, located on the sides of the axes of each entity's maneuvers. The defined restricted zone creates tactical spacing between the axes of the formation maneuvers. Its width can be variant-adjusted for each tactical element. The total width of the impassable zone, double-sided from the calculated axis of the maneuver, may take values such as 50 m for a UGV, 100 m for a squad or army tank, 200 m for a platoon and 400 m for a company. The value of the distance of this restricted area on the sides of the maneuver axis from the target enemy's position can be adjusted into the calculation depending on the distance requirement for maintaining tactical spacing when deployed in a pre- or post-combat formation.

The MCS CZ group maneuver model can be used both in calculating the assumed variant of the enemy unit maneuver and for the maneuver of friendly units. Using it, one can identify the likely axes of maneuvers of enemy units, the narrowed points with anticipated increased concentrations of units, and the areas deployed in the battle formation. Based on the results thus calculated, it is then possible to identify the target positions of the counter-maneuver reaction of friendly units. Applying the MCS CZ, it is then possible to calculate the axes of the counter-maneuver and its execution time. It is feasible to model different variants in the development of the situation on the battlefield by means of variable changes in the input characteristics of the MCS CZ, such as the deployment of enemy units and obstacles, or changes in the speed of redeployment across different types of surface.

The MCS CZ is primarily focused on solving tactical situations on the battlefield, in which it is necessary to make decisions quickly and under time pressure based on the analysis of most of important influences of the situation. The axes of the maneuvers are calculated as the fastest and safest, which corresponds exactly to the offensive maneuver of the enemy forces as well as the possible reaction of friendly forces. The time and safety of the maneuver is, therefore, a priority evaluation characteristic. In military practice, the MCS CZ can be used especially in the situations when enemy and friendly forces need to perform an offensive maneuver, retreat or move from the target position with

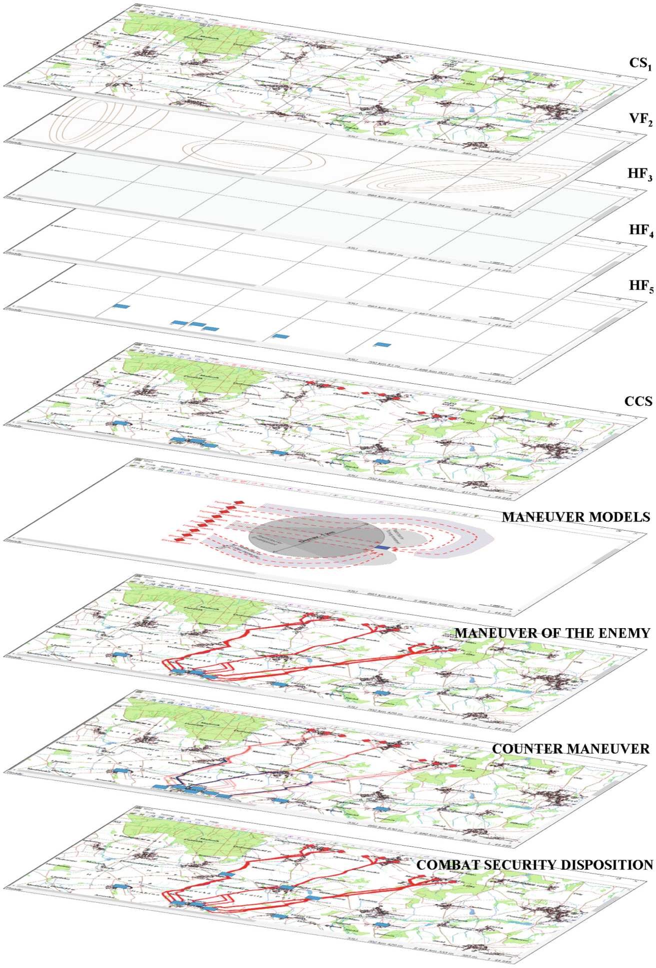

Fig. 1. Information layers of the MCS CZ

a minimal risk of attack by the enemy and in the shortest possible time. Some of them are described in [35–37]. The MASA SWORD simulator can be used to validate the maneuver axes and times calculated by the MCS CZ, as an alternative to the actual execution of maneuvers by units in the field.

3 Case Study: Modelling the Enemy Course of Action

In the following case studies, calculating the maneuver axes of both the attacking forces of the enemy and the reaction maneuvers of friendly forces using MCS CZ and the MASA SWORD simulator are compared. The purpose of this comparison will be to verify the ability of the MCS CZ to generate real axes of maneuvers and times to cover them that are usable in a war game. Digital land and relief models, including mathematical algorithms to assess their passability and tactical maneuver models, have already been stored in the system. Specification of weather conditions and the tactical situation on the battlefield, including unit positions and the tactical technical data of weapon systems in the MCS CZ can take an experienced operator 10–20 min, depending on the extent. Calculating the axes of each maneuver are then performed in a matter of seconds.

In a tactical situation scenario, enemy forces advance in the attack direction from the north to the south, between two smaller towns at a distance of approximately 20 km. They are made up of three battalions totaling nine companies of motorized infantry, using wheeled infantry fighting vehicles. The band of advancement is made up of undulating terrain relief, farmed land, with densely scattered villages. It is bounded naturally by woodland, further to the east by a river and to the south by hilly terrain, with an average width of approximately 6 km. Weather conditions were simulated as the previous 3 days without precipitation, clear, 20 °C, light wind 5 $m.s^{-1}$.

Halfway across the enemy's advance zone, our friendly units rapidly took up a line of defense, with the task of slowing the enemy's advance until reinforcements arrived. It is planned to create a heavily defended area in the village at the center of the line for this purpose. Enemy units preparing to advance southward must surmount this heavily defended area. They can make an attack either from marching, after a shortened preparation, or after a full preparation. The attack from marching represents a steady continuation of the advance on the planned course of attack, using speed and the element of surprise in attacking the rapidly engaged, unprepared defense of friendly forces. This option may be the most dangerous for the defending units, as the rapidly engaged defense of friendly forces will not be reinforced by engineer-built defensive structures, explosive and non-explosive barricades, or the prepared efforts of artillery and air support. However, the enemy will have to surmount the space between the current deployment of enemy troops and friendly defense forces as quickly as possible, depending on terrain passability and the capabilities of one's vehicles and weapon systems.

Modelling the progress of the maneuvers of enemy units seeking to breach the heavily defended area in the village can be done using the MCS CZ. The enemy's cooperating units are divided into three groups (battalions) of three motorized companies. The axes of maneuver of each unit are calculated on the basis of the impact of the surface and the relief of the terrain, the weather, and the actual deployment of enemy units and friendly forces in two variants – as tactical and fastest. The axes of tactical maneuver are shown in Fig. 2 in red and represent a maneuver in the tactical formations of the units with mutual security and control of space. The axes of fastest maneuver are shown in yellow in Fig. 2 and are mainly led using paved roads that allow maximum maneuver speeds to be reached.

The anticipated time constraints for the execution the enemy's maneuvers was calculated at 34:00–38:23 min for the Eastern Battalion Task Force, at 29:00–33:37 min for the Central Battalion Task Force and 32:51–36:11 min for the Western Task Force.

The speed variables are set to be the highest average for a tactical maneuver of a particular type of combat technique in a space where contact with enemy units is likely. The speed values take into account the nature of the specific terrain surface, the technical capabilities of the vehicle, the mutual coverage of the vehicles and control of the surroundings, in order to identify enemy forces in a timely manner and minimize the risks of destruction. Their values have been generated based on the author's practical experience in driving combat vehicles and commanding maneuvering units within military exercises, and are shown in Fig. 3 on the left. Their values may vary in variation depending on the field conditions, type and state of the technology, and the tactical situation on the battlefield. Larger bodies of water and streams are generally considered impassable in the MCS CZ due to the significant risks of loss of mobility and combat capability caused by the nature of the bottom, banks, depth and speed of the watercourse.

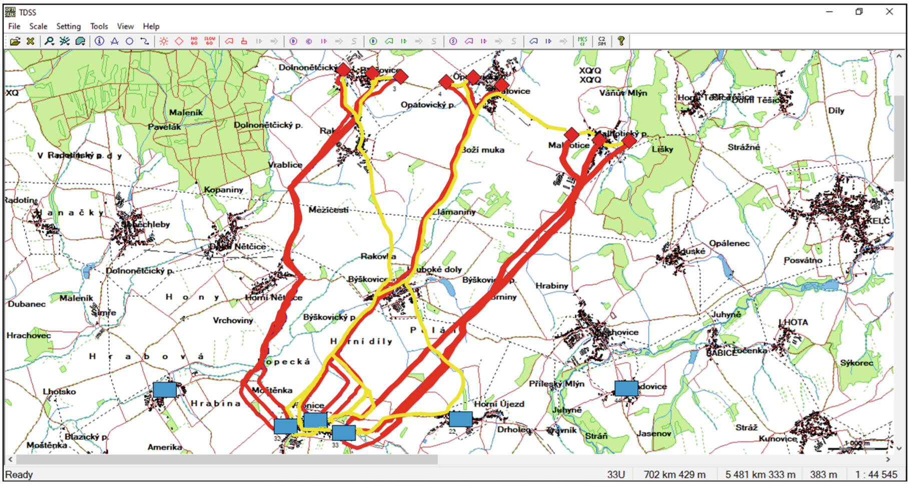

Fig. 2. Enemy courses of action [TDSS – adjusted] (Color figure online)

For the variant of the fastest enemy unit maneuver, the MCS CZ enemy approach times to friendly units in defense were calculated at 8:31–15:35 min for the Eastern Battalion Task Force, 6:31–11:52 min for the Central Battalion Task Force, and 7:04–11:25 min for the Western Task Force. Speed variables are set as the fastest possible speeds on the types of terrain considered. Their values were measured in experimental testing, described in [30], and are shown in Fig. 3 on the right.

In the event of a tactical approach by enemy companies into a heavily defended area of friendly forces, initial contact can be expected from the center of its formation in approximately 29 min from launch. It can therefore be assumed that a rapidly engaged defense of friendly forces has a minimum of 29 min to retake defensive positions or deploy roadblocks and combat security units.

In the event of the enemy's fastest possible approach into heavily defended space, as the most dangerous variant of enemy activity, first contact can be expected from the center of the enemy's formation in approximately 6:31 min. To do so, the enemy is likely to use two roads in particular, running through the center of space. Most of the enemy unit's maneuver is then likely to be surmounted by moving along the road in a flow, and deploying them off the roads will occur outside the perimeter of the defense area. The short approach time does not even allow for the basic deployment of the main weapons of friendly units, including any subsequent build-up of a defense fire system. Unless the

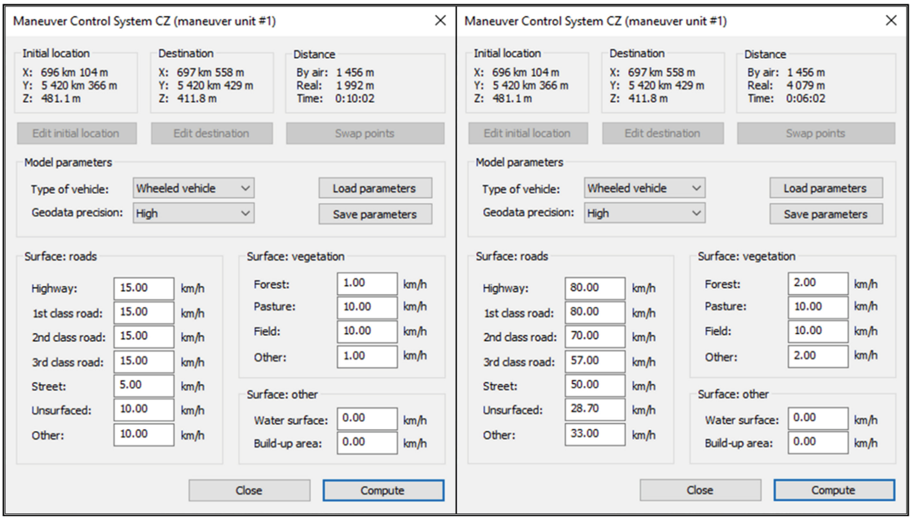

Fig. 3. Speed variables [TDSS]

commander of friendly defense forces is able to use massive air or artillery support to stop the enemy's rapid advance, their forces are unlikely to be ready for any kind of defense of the area. One solution could be to send combat security units into temporary defensive positions in order to slow the advance of the enemy and identify its approach directions.

4 Case Study: Modelling a Friendly Forces Counter Maneuver

Friendly forces have rapidly established a line of defense and are expecting an immediate attack from the enemy. However, they are not simply static, but seek to actively adapt the combat set-up structure for combat provision, due to an early warning about the enemy units attacking, forcing them to deploy prematurely. They can also take advantage of e.g. the setting up of roadblocks or the pre-planning of artillery and air support areas, see [38, 39]. Using mathematical calculations and axes modelling of the offensive maneuver of enemy units, one can estimate their probable course and length of time. In the event that friendly forces are still not in contact with the enemy, but are trying to act proactively and estimate the current position of its units, the MCS CZ allows you to calculate the fastest safe axis for the predicted maneuver of enemy units. Based on this, the commander is able to send smaller combat security units to the precise areas of anticipated concentration of the enemy's maneuver axes. The objective of these units is to rapidly engage in advantageous spaces and lines to slow the maneuver of the enemy units. Similarly, it is able to prepare and plan in time for the action of combat support units against the maneuver of the enemy, into the areas of anticipated concentration of enemy units.

As a variant for the activity of friendly forces 2 (COA2), combat security unit detachments will take up their planned positions at times: 13:12 min eastern unit, 14:02 min central unit, and 17:06 min western unit, in case they move out immediately after launching an attack by the enemy. The axes of maneuvers of the three combat security detachments were calculated at their defensive positions, at a direct distance of 2,697–3,132 m from the starting positions, graphically shown in dark blue in Fig. 4.

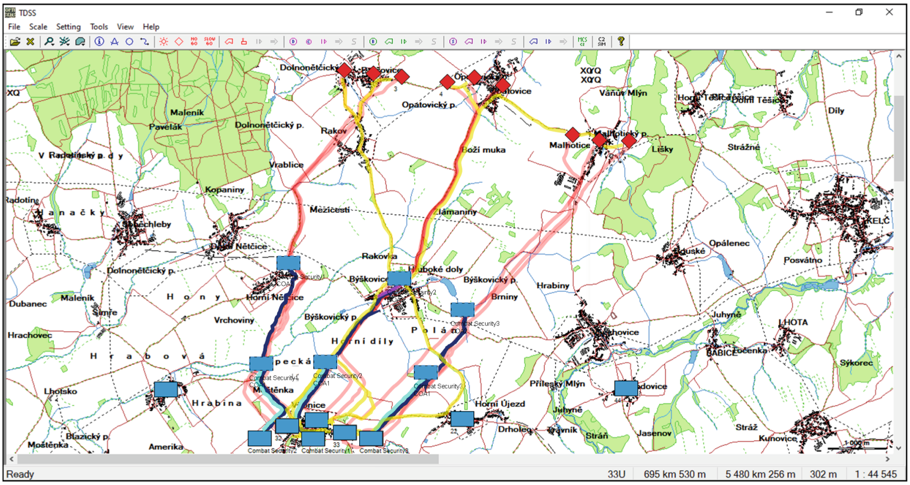

Fig. 4. Counter maneuver of friendly forces [TDSS – adjusted] (Color figure online)

In the case of a lack of time, when enemy forces have already taken over villages located to the north of the line of defense, friendly combat security units can be alternatively deployed to a position about half the original planned distance. In Fig. 4, these maneuver axes are graphically shown in light blue and identified as COA 1. Even with this option, rapidly engaged defensive positions are situated in spaces with assumed concentrations of the maneuver axes of enemy units. Defensive positions in these locations may be located in smaller woodland areas or behind a terrain barrier that provides cover and concealment. The combat security detachments are, based on geographic and meteorological characteristics of the terrain, able to take the COA1 defensive position at 7:06 min eastern unit, 5:52 min central unit and 6:38 min western unit. All three axes of maneuver of these units are identical to those of the COA2 maneuver, but they are only driven to a direct distance of 1,203–1,403 m from their starting positions. The advantage of COA1 is a faster execution over a shorter distance and the possibility to use the support of units at the strongpoint of friendly forces, including their cover when withdrawing under enemy pressure.

5 Comparing the MCS CZ Calculation and the MASA SWORD Simulation

MASA SWORD is a complex analytical tool designed for the automated constructive simulation of various tactical scenarios in user-defined field conditions powered by artificial intelligence. For simulation, it uses height, raster and vector geographic models of space as a base. It allows you to simulate a number of variable situations in highly realistic environments, such as military conflicts, stabilization operations, terrorist threats, or natural disasters. It includes the server environment, a simulation client, a time sheet, scenario preparation tools, the ability to customize physical and decision models, simulation evaluation tools, and stand-alone preparation, including a web environment for operating on a network of computers. All features can be set up in the simulator, ranging from vehicle speed, weapon system activity, and sensor accuracy, through unit composition and logistical security, to a doctrinal model of activity and combat tasks, see [40]. Units and weapon systems can operate completely autonomously on the battlefield. SWORD allows them to give an order that they follow without the need for any interference from the user. MASA SWORD has been used by the University of Defence of the Army of the Czech Republic since 2020.

The tactical situation described above, the variants of its development, as well as the options for resolution have been defined in the simulator. The same units (motorized companies) were used on both sides of the simulated tactical situation, armed with wheeled infantry fighting vehicles and infantry soldiers with identical characteristics. A variant of the axes of tactical approach and attack by enemy units is shown in Fig. 5. The progress of the maneuvers of enemy units as calculated by the MASA SWORD in the tactical variant is not entirely consistent with the MCS CZ calculations. This may be due to the different geographic background, a divergent speed setting for much greater variability in the MASA SWORD surface types, and an attack being carried out within a defined spatial band.

In the case of calculating the fastest variant of the maneuver axes, in MASA SWORD these are for the most part led along two paved roads in the center of the space, identically evaluated by the MCS CZ. The initial direct distance between friendly forces' defensive positions and the enemy units was approximately 6,500 m. The calculated fastest time for the enemy to reach friendly units' defensive positions was 29 min in the MCS CZ, namely a battalion company in the middle of the enemy's offensive lineup. A possible reaction of friendly forces was to send in combat reinforcements in order to create the conditions for a defense buildup and early warning. Calculations of the axes of enemy maneuvers into the space of the captured strongpoint and the planned defensive positions of combat security with COA1 and COA2 are shown in Fig. 5 for comparison and supplemented by the execution times in Table 1.

Horizontally, the times shown in Table 1 are divided according to the target areas of the maneuvers, and vertically by which units are performing the maneuver. The units' maneuver times into specific areas are further divided according to the method and especially the speed of its execution into tactical and the fastest.

The comparison of the resulting maneuver times, calculated in the MCS CZ and MASA SWORD in Table 1, identifies insignificant differences. The times calculated by MASA SWORD are generally of a greater value than the analogous variant calculated in the MCS CZ. This may be due to different underlying geographic data and, for MASA SWORD, more detailed speed specifications on a larger number of terrain surface types and applying a doctrinal model for the combat activity of the enemy units. The greatest time variation was recorded in the variant of deploying friendly combat security

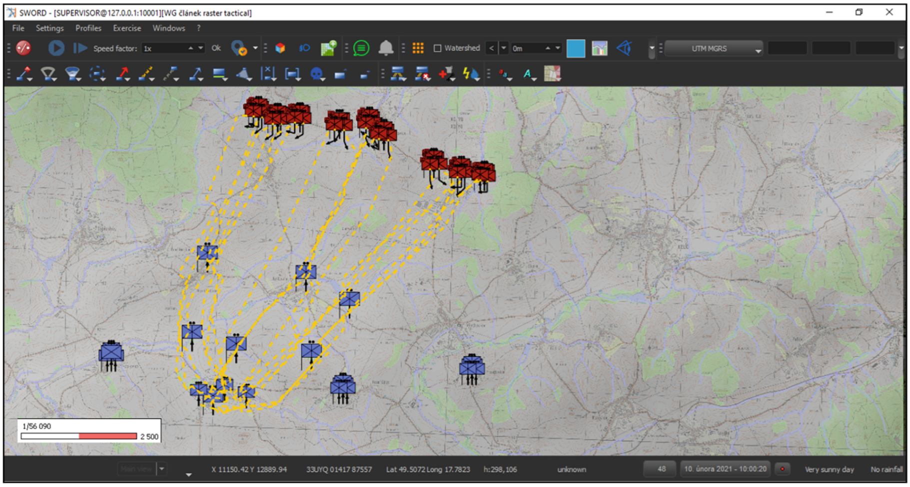

Fig. 5. Tactical variant of enemy attack [MASA SWORD]

Table 1. Maneuver of the first-line companies [MCS CZ, MASA SWORD]

	Method of implementation	Space of strongpoint			Combat security COA 1			Combat security COA 2		
		West	Center	East	West	Center	East	West	Center	East
Execution time of friendly forces' maneuver MCS CZ	Tactical	0	0	0	6:38	5:32	7:06	17:06	14:02	13:12
	Fastest	0	0	0	2:56	1:37	4:50	6:14	3:26	5:44
Execution time of friendly forces' maneuver MASA SWORD	Tactical	0	0	0	7:40	4:50	8:10	18:54	16:00	14:50
	Fastest	0	0	0	3:20	1:52	5:53	7:08	4:10	6:50
Execution time of enemy forces maneuver MCS CZ	Tactical	32:51	29:00	34:00	27:33	23:30	25:56	17:30	14:28	20:30
	Fastest	11:55	6:31	12:41	8:37	5:47	8:31	4:08	4:02	7:04
Execution time of enemy forces' maneuver MASA SWORD	Tactical	33:28	30:46	35:24	28:47	24:20	26:40	18:22	15:20	21:45

(*continued*)

Table 1. (*continued*)

	Method of implementation	Space of strongpoint			Combat security COA 1			Combat security COA 2		
		West	Center	East	West	Center	East	West	Center	East
	Fastest	12:26	7:10	13:20	9:16	6:05	9:07	5:02	4:50	8:21
Execution time of enemy forces' maneuver MASA SWORD while taking COA2 position by friendly forces detachments	Tactical	53:34	51:00	56:10	42:10	40:20	44:00	24:10	22:10	28:10
	Fastest	19:49	23:20	25:10	14:38	17:20	20:20	7:30	8:23	12:30

detachments in position with COA2 prior to the commence of the enemy attack, when a doctrinal model also enters the maneuver simulation.

6 Conclusion

In case studies, using the MCS CZ and MASA SWORD, the axes of the enemy units' offensive maneuver were calculated in the fastest and tactical variants of execution, advancing over rapidly engaged defenses of friendly forces. Using mathematical algorithmic models and digital data of territory and relief, it was possible to generate axes of unit maneuvers while dealing with time-constraint situations on the battlefield. Evaluating terrain passsability and calculating individual maneuver axes in the tactical situation took several seconds using the MCS CZ and MASA SWORD. They produced the fastest passable axis of maneuver to the target, calculated depending on speed parameters. The resulting COA can be modelled in a variable way, taking into account changing developments in the battlefield situation, information currently gathered about the enemy, or changes in the weather.

Based on the results of the war game conducted using the MCS CZ, a variant of the actions of friendly units can be chosen in a situation induced by the case study.

In the event that the enemy decides to proceed immediately in the direction of the attack, the first contact with its combat units can be expected, according to the MCS CZ, most likely in 29 min when implementing the tactical variant. However, when implementing the worst – i.e. fastest – variant, friendly units in defense can be attacked in as little as 6:31 min. The enemy forces outnumber friendly and have a high degree of mobility, and for that reason friendly units have rapidly taken up defense. For early warning, combat security units in the strength of three reinforced squads have been assigned to take up planned defensive positions in two COAs. In the case of the closer COA1, based on the MCS CZ calculations, defensive positions can be taken in time using tactical secured redeployment, without the risk of being attacked by the motorized companies of the enemy. However, in the case of applying COA2, it is necessary to use the fastest possible means of taking up combat security defensive positions in order to prevent the occupation of these spaces by the enemy. But even with the fastest means of engaging the COA2, the planned western defensive position may be overrun by the enemy two whole minutes prior to the arrival of friendly combat security unit, based on the MCS CZ calculations.

As a solution to this tactical situation, it is therefore advisable to take up the COA2 positions as fast as possible, provided there is constant monitoring of the area by means of aerial reconnaissance. In the case of identifying enemy presence in the COA2 position area, the combat security units would deploy or retreat to defensive positions on the COA1 under pressure.

The differences can be identified when comparing the calculations of axes and maneuver execution times using the MCS CZ and the MASA SWORD. Even so, the calculated axes of maneuvers in both programs confirmed the tactical correctness of the deployment of the combat security units in the COA1 and COA2. The implementation of individual MCS CZ maneuvers was mostly calculated faster than calculations done with the MASA SWORD simulator. Based on the results mentioned above, calculations of the MCS CZ can therefore be considered the COA under the so-called "worst case scenario" of the enemy forces maneuver. The worst-case scenario of the enemy COA for a battlefield situation is a very common commander's approach when planning and implementing the countermeasures of friendly units in military operations.

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