Modeling of Infantry Attacks on Real Terrain

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Abstract. The estimation of the terrain features can be completely carried out by using the Geographical Information System (GIS). GIS technologies and three-dimensional map in planning battle tactics are discussed. An infantry attack on real terrain is modeled. The stochastic model of combat is given in article.

Keywords: modeling, military operations, stochastic models, Geographical Information System.

1 Introduction

At present capabilities of Geographical Information Systems (GIS) are more and more widely used in planning military operations. The analysis and control of the movement of military means of transport, while applying the Arc View program packet, was presented in the article by Kim and Park [1]. S. Crino [2] pointed out that force structures have to more frequently operate in urban areas. He in detail explored all types of operations, from the point of view of essential operational aspects surveyed and estimated current algorithms and models of operations, development of new structures, their advantages and disadvantages. The overview of visualization strategies of the virtual geographic terrain and their application in different areas of warfare practice was presented in the study by Feibush et al. [3–9].

This article discusses the employment of modern information technologies in planning and estimating the capabilities of a military unit to execute a certain task. A system of "program tools", created by using GIS information bases, makes it possible to carry out the engineer estimation of the terrain, obtain data on the network of roads, water bodies, vegetation, building structures and qualities of the soil. A visibility instrument has been created and it provides a generalized “visibility matrix”, i e. indicates visibility on the battlefield from several chosen terrain places. A program describing infantry combat actions considered. Actions of each individual soldier on the battlefield are modeled, the impact of random factors is estimated, and a ”digital experiment” of a would-be attack is carried out. The employment of mathematical modeling makes it possible to estimate the capabilities of a military unit fighting on a concrete terrain and to foresee ways for decreasing casualties in executing a combat task.

2 Application of GIS technologies in engineer estimation of the terrain

The main information source about the terrain is sheets of digital map with the scale of 1:10000. The entire standard information of the digital map is based on a slightly-associated integration between the packets of geographical information systems and relation data base. This integration is necessary in order to uniformly process both the geometrical information and attributive information of space objects.

2.1 Criteria of the engineer estimation of the terrain

Engineer estimation of the terrain takes these criteria into consideration:

a) a network of roads. Readily available roads make the movement of military transport much easier;

b) water bodies: rivers, canals/channels, lakes. Information about bridges;

c) a map of the flatness of the terrain surface. Usually such a map is non-existent. It is necessary to draw it by applying attributive and spatial information of the relief;

d) a map of terrain utilization. Three categories are sorted out (built-up areas, forests, arable fields);

e) a map of soil qualities. These qualities should be pointed out: soil humidity and the permissible load, cross-country capability.

2.2 Information of the engineer estimation of the terrain

GIS information layers are created by using spatial information of the terrain according to the requirements for a concrete military operation. To this end the necessary program “tools” were created.

The network of roads, rivers, bridges

The created tool of road analysis makes it possible to organize dynamic inquiries in order to find roads satisfying certain criteria. The necessary information is automatically provided by the electronic map. Having activated this tool, it is sufficient to circle the area of interest and the system points out all the roads of the chosen width. Road surface, number of lanes and other attributes such as the name, code and number of the road inherent in the system are shown. When the arrow is on the bridge of your choice and the button is pressed, the information about that bridge is supplied: the length, lifting capacity, etc.

The map of the terrain utilization

All the terrain in the information system is divided according to the utilization type: settlement, arable land, forest. The tool of forest analysis makes it possible to get information about large forest areas. Its operation is similar to that of the road analysis tool – the area is marked and the tool automatically selects forests existing in that area (see Fig. 1).

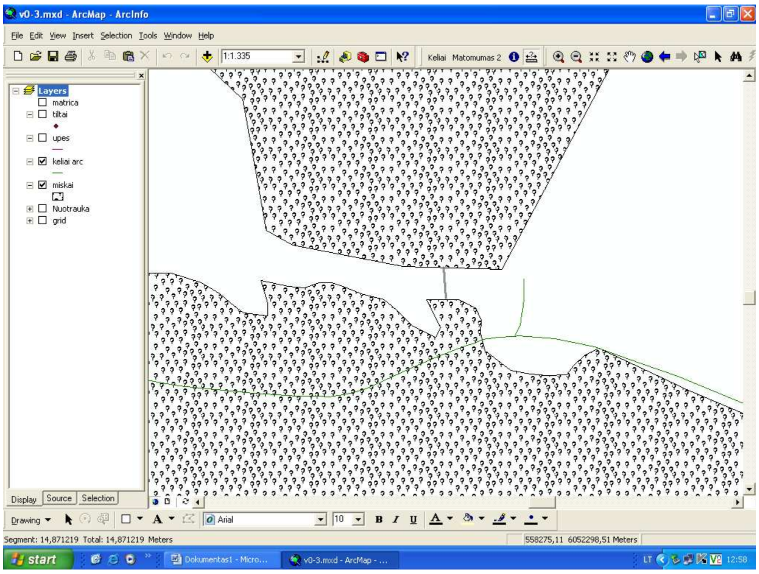

Fig. 1. Width of the clearing indicated by the arrow is found.

Having indicated the place with the help of the button, the information about the thickness of trees, the density of the forest is provided. Having chosen the measurement tool, it is possible to estimate the width of the clearing and obtain information on the cross-country capacity of the terrain.

The map of the soil

A standard engineer estimation of the terrain procedure takes into account the type of soil of a concrete terrain. Our currently available digital maps did not provide information about the soil; therefore, in this concrete case, that layer was not created.

Each individual tool generates its own individual information layer (an individual map). It is also possible to get an image combining all the above-mentioned information, a general image. Thus, it is possible to have all the necessary engineer information.

2.3 Visibility on the terrain

GIS information bases hold data about the height of objects on the terrain. A height analysis tool was created which automatically gets information from the electronic map bases and then provides information about the visibility in the designated terrain. Having summoned the visibility tool, the coordinates of the bottom left and upper right point of the desired-to-see square are indicated (it is possible to "circle" this area with the mouse, but the first mode is more exact) followed by the coordinates of the terrain observation point and the image of visible (green) and invisible (red) areas is provided (see Fig. 2). The observer's point was designated by X, the place visible to him – 1, the invisible one – 0. The distance between the points in the horizontal direction (longitude) is ≈ 10 m, in the vertical one (latitude) – ≈ 17 m.

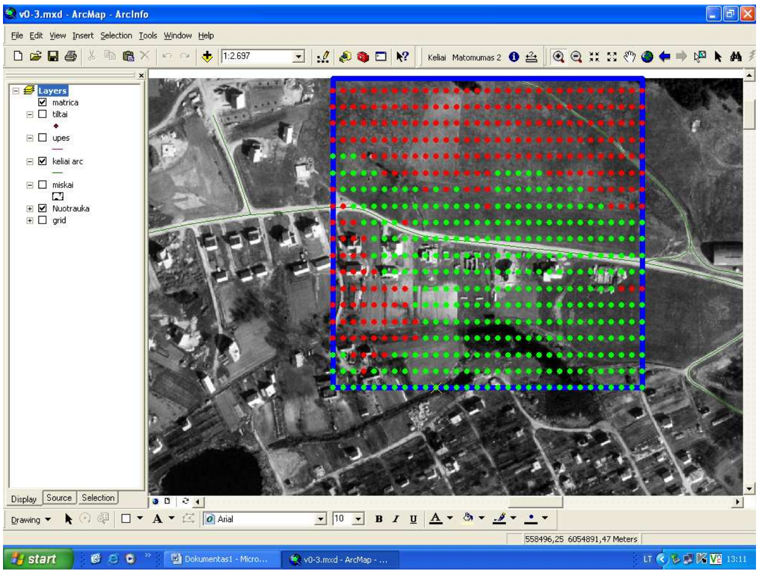

Fig. 2. Image of the terrain and work results of the visibility tool: visibility from the designated X point.

At the same time, a visibility matrix is created (visible points are marked by 1, invisible points by 0, see Fig. 3).

Let's say that ten soldiers are fortified and are about to be attacked by a three times larger force – 30 soldiers. In order to obtain a visibility matrix of the fortified adversary, it is sufficient to know the visibility from 5 points (for each pair of soldiers) and to create a generalized visibility matrix. The created MAPLE program executes the generalization procedure, i.e. it creates the visibility matrix of all the defending soldiers. Such results are shown in Fig. 4. The distance on the terrain between the visibility points in the horizontal direction (longitude coordinate) is equal to 10 m, whereas in the vertical direction (latitude coordinate) it changes to 16 m. It should be pointed out that on real terrain the visibility (objects exceeding 1 m in height are seen) seldom exceeds 300–400 meters. This generalized visibility matrix is used in solving the attack task by applying the stochastic method. The attacking soldiers move along the lines designated by matrix columns and we get the information stating whether the adversary can see a concrete soldier.

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1 1 1 1 1 1 1 1 X 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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Fig. 3. Results of the visibility tool analysis.

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xx  xx  xx  xx  xx   xx  xx  xx  xx  xx  xx  xx  xx   xx  xx
1 1 1 1 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
1 1 1 1 0 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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               xx   xx   xx    xx   xx
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Fig. 4. A generalized visibility matrix. At the top, pairs of attacking soldiers are formally designated, at the bottom – those of defenders. The distance between the fighting parties is about 300 m.

3 Modeling of combat actions

Depending on how the combat process description proceeds, mathematical models are divided into two main groups - analytical and stochastic. In the former case, differential equations describing combat process are written down (for example Lanchester model) and analytical or numerical solutions are obtained. Combat actions are very complex and are affected by numerous random factors; therefore, to describe them by using analytical representations is often practically impossible. For this purpose statistical models and the Monte-Carlo model are used. This method makes it possible to find the interaction result between the modeled objects when the relations between them are either unknown or very complex [10, 11].

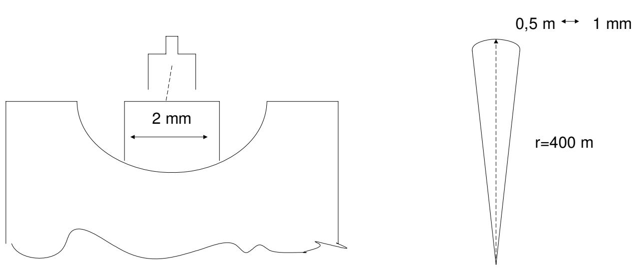
Modeled actions of soldiers: movement towards the adversary, observation and detection of the adversary, firing and elimination of the adversary. Similar actions of the adversary are modeled: detection of the attackers and actions to eliminate them.

3.1 Hit probability

In case of rifle shooting, the probability of hitting the target depends on the distance to the target, type of weapon, accuracy of the soldier, meteorological conditions, and other factors. Deviations are distributed according to the two dimensional normal distribution presented by the formula:

$$p_g(r) = \frac{1}{\pi\sigma_x\sigma_y}\int\limits_{x_1}^{x_2}\int\limits_{y_1}^{y_2} e^{\frac{(x-x_m)^2}{2\sigma_x^2}} e^{\frac{(y-y_m)^2}{2\sigma_y^2}}\,\mathrm{d}x\,\mathrm{d}y, \tag{1}$$

where $[x_1; x_2]$, $[y_1; y_2]$ are intervals that indicate the size of the target, $(x_m; y_m)$ are coordinates of the aiming point (distance from the weapon to the target), and σ_x and σ_y are average quadratic deviations, that are determined by weapon design features. The situation when aiming at a soldier from a 400 m distance looks about like this (see Fig. 5.).



(a) (b)

Fig. 5. Diagram of aiming from a 400 m distance.

The back sight of the rifle, AK, is at the distance of approximately 80 mm and is

2 mm wide. The figure of the soldier (0.5×1.5 m) from the distance of 400 m looks 1 mm wide. The result is considered positive if the moving target is kept within the zone of the sight (4 mm). In this case, the interval $[y_1; y_2]$ in the formula (1) is considered equal to 2 m. The position of the enemy figure (see Fig. 5) can be chosen at any place of the sight notch zone (soldiers are trained to move on the battlefield to possibly avoid an accurate enemy shot). In a concrete case, we divide the zone into only ten equal parts, because the result does not change if we increase the number of divisions, using formula (1) work out the hit probability in each case and afterwards compute the average of these probabilities [10,11]. The impact of the wind can also be included into these computations (the data as to how much the wind of a certain speed diverts the bullet are usually known). For example, a medium-strength wind ($\nu = 4\mathrm{m/s}$), perpendicular to the firing plane, with the firing distance of 400 m, diverts the AK74 bullet 0.5 m to the side [12]. The interval along the direction of shooting, i.e. along axis x direction, is equal to the range of a point blank shot when the whole trajectory of the bullet does not rise above the target. Fig. 6 presents the computation results.

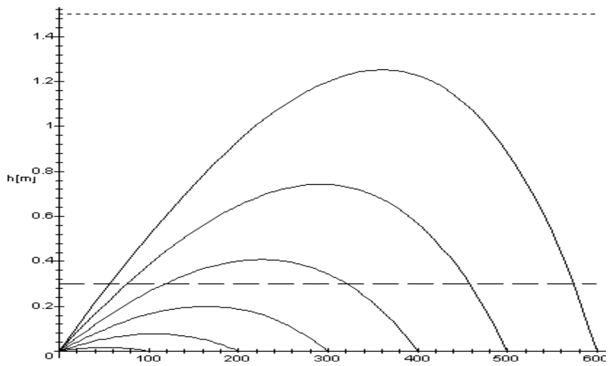


Fig. 6. AK74 bulletF4 trajectories when shooting from 100 m to 600 m distance. The top line corresponds to the shadow height of the attacking soldier – 1.5 m – and the bottom line to that of the defending soldier – 0.3 m.

If a bound (moving in bounds on the battlefield during the attack) lasts 2–4 seconds, and the adversary needs 5 seconds to take aim, the hit probability decreases. Its change can be estimated by employing the formula that is widely used in the queueing theory:

$$P_i(r) = 1 - e^{\frac{P(r)t_i}{t_0}}, \tag{2}$$

where $P(r)$ is mean hit probability when target distance is r, t_0 is the average time during which a soldier manages to take aim, t_i – stands for a random time interval (the time of the bound), for example 2–4 seconds. Having completed the above-mentioned computations covering six points (every hundred meters), we generalize these computations by using the method of least squares (see Fig. 7).

Soldiers bearing automatic rifles choose enemy soldiers firing at them or those that are nearest to them and shoot by taking aim. Machine gunners fire partially taking aim or conduct area firing; grenade launcher and mortar fire usually destroys group targets or heavy weapons.

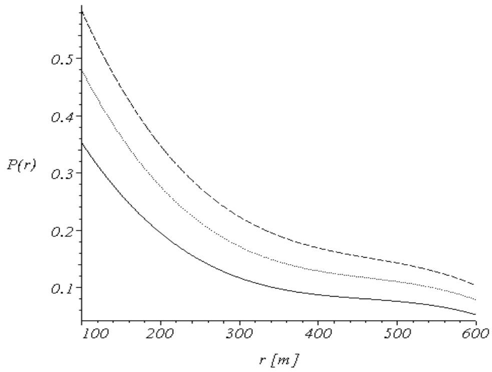


Fig. 7. Dependence of hit probabilities on distance in offence if the bound time is: line – 2 s, dots – 3 s, strokes – 4 s.

3.2 Programs simulating the course of the battle

Essential actions of attacking soldiers in battle are modeled: movement towards the adversary, observation and detection of the adversary, firing and elimination of the adversary. Similar actions of the adversary are modeled: detection of the attackers and actions to eliminate them.

If the visibility scheme of soldiers' fighting in visibility defense corresponds to Fig. 4, the attacking soldiers at such a short distance are spotted right away. They are visible provided the terrain features do not impede. Let's assume that the attack began after dismounting from combat vehicles at an approximately a kilometer distance from the suspected defense position of the adversary. Platoon in attack covers about a 300 m long strip and soldiers move towards the enemy maintaining $d \approx 8 \div 12$ m distance between one another. The direction of the soldier movement and his visibility in attack are indicated by the elements of the matrix (see Fig. 4) columns (1 – is seen, 0 – not seen). If soldiers engage in battle $\Delta t_1 \approx$ 3–4 s (leaving adversary no time to take aim) at a random moment of time $\Delta t_2 \approx$ 14–16 s, we will analyze the movement changing the time at $\Delta t = Deltat_1 + \Delta t_2 \approx$ 18–20 s intervals. This type of movement can be described as a re-location to another square (the sides of the squares are 17×10 m). We will make an assumption that within such a slight distance interval the visibility, relief and other conditions will change insignificantly.

It is possible to analyze different battlefield movement schemes, For example, with the platoon in attack, at first one team moves in a bound ($\Delta t_1 = 4$ s, whereas in defense, a soldier takes aim and becomes a target himself $\Delta t_1 = 5$ s) while the other two cover it by fire. After that, two teams in a bound level the attack line while the first team covers them (see Fig. 8).

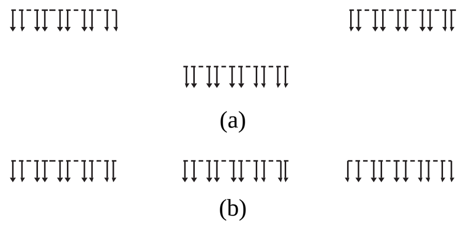


Fig. 8. Scheme: (a) the middle team rises for a bound, the remaining two cover by fire; (b) flank teams rise for a bound, the middle team covers by fire.

Whether a concrete event has taken place is tested this way. For example, if the hit probability p in a concrete case is equal to 0.4 ($p = 0.4$), the random variable r_u distributed according to the uniform law within the interval $[0;1]$, is generated and the condition:

$$r_u \leq p \tag{3}$$

is checked. If the inequality (3) is satisfied, it is considered that the event has taken place, i.e. "the target has been hit". If it is not satisfied, the event has not taken place. Afterwards the results are summed up, casualties and numbers of personnel further participating in the attack are counted. This is repeated until the battle ends, i.e. the time allotted for the battle ends, more than half of the personnel are killed, etc. Thus the results of one realization are obtained. Such computations are repeated 100–200 times and the average of the results is found (each realization is different because ever different random variables are generated) for each computed time moment (point). The number of realizations is increased until the obtained answer stops changing though the number of realizations is further increased with the indicated computation accuracy. Computation results of such a model of the attack are presented in Fig. 9.

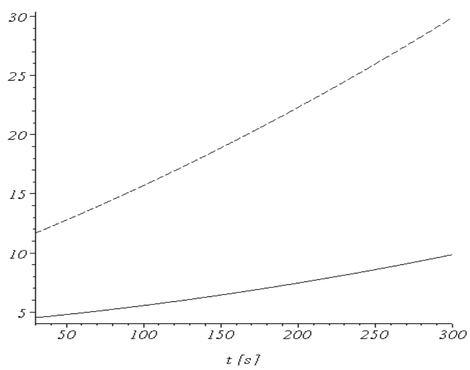


Fig. 9. Change in the number of attacking (stroke line) and defending (line) soldiers during the attack. r is the distance between the adversaries.

4 Conclusions

Accurate and timely estimation of the reconnaissance battlefield terrain is a prerequisite for effective control of modern and rapid military operations. Application of traditional technologies for the solution of this problem is not effective because at present digital maps and digital terrain images, made by great resolution satellites, are available. Employment of GIS information makes it possible to create effective visual maps in accordance with various requirements. These digital maps can provide expert knowledge while a cadet is carrying out a specific military operation.

Generalization of the data received leads to these conclusions:

1. The developed programs make it possible to describe concrete combat actions of the soldier and analyze the impact of numerous random factors on the course of the battle. For example, the beginning of the attack, the duration of the bound, tactical elements (different movement types of soldiers on the battlefield, coverage by fire from the flank, etc.).

2. To estimate the impact of the terrain, the individual tactics of the military personnel and movement on the course of the battle. Accurate and timely engineer estimation of the terrain is a prerequisite for effective control of modern and rapid military operations. Employment of digital maps and digital terrain images, made by great resolution satellites, make it possible to carry out an effective analysis of the battlefield.

3. To accurately count military ammunition expenditure, to estimate the demand for it in order to reach the desired result.

4. It is possible to analyze the impact of different weapons on the course of the battle.

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