A DECISION-MAKING TOOL TO MILITARY PLANNING PROCESS BASED IN DYNAMIC-COST MATRICES

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Abstract

This work presents terrain and power projection models of a troop considering the terrain. Such models are then integrated into a cost matrix that is used in a shortest-path algorithm. From the moment the itinerary is being defined, the confrontation between the troops positioned on the terrain and those being displaced is computed. According to such contact, the matrix of the combat power is altered, and consequently the cost matrix. We present an algorithm to define the smallest-cost path considering cost variation in the resulting image. The results obtained, in terms of displacement time and distance and troop losses, will be used to quantify variables considered in the decision-making procedures of a Military Planning Process.

INTRODUCTION

Military Planning Process (MPP) is a tool for analysis and synthesis of military problems. At present, this tool can deal with a high degree of subjectivity in some stages or phases of its development.

The present work seeks to support the decision making, providing quantified parameters related to the time and distance analysis of the progression of Marines in a terrain controlled by enemy troops.

To achieve the proposed goal, we will work with models and concepts already defined in several areas of study, integrating them.

We model the terrain using a trafficability map in which the color intensity of the pixels is proportional to the difficulty of a troop of a certain nature to traverse it. The terrain influences the engagement time of the troops, causing a variation in the power projection image. The final form of the model will be a terrain-cost matrix (image), based and constituted by part of the terrain model used in the Warfare Games Center of the Almirante Sylvio de Camargo Instruction Center, Brazilian Navy Marines Corps.

The combat power projection of a defensive troop that statically positioned on the terrain is modeled according to the amount of ammunition, weaponry, observer-target distance, and main observance position, generating an image whose tone differences represent the power projected over the influence areas [2]. Like the terrain model, the output of this phase is a matrix with the same dimensions as the terrain matrix, containing costs related to the positions where the combat elements project their power and a zero cost where there is no combat power. Such costs are computed employing derivations from T.N. Dupuy's models and will degrade (decrease) with the contact between opposing forces, thus requiring a continuous process [1].

The terrain and the combat-power projection models are related with a scale compatible with the influence each model must have in the result expected by the system user. To study this relation is to evaluate its coherence with reality.

We have implemented a shortest-path algorithm for the modeled matrices, considering the combat-power variation of both defending troops and offence troops according to the distance between them and their estimated time for contact. We can then evaluate whether the final result will allow a quantitative estimation of some aspects of the confrontation, considering all variables involved in the proposed problem, thus supporting the decisions of the officer using MPP.

MODELS

In this work, two types of models are used for the terrain. The first is related to the elevation and the second to the speeds a troop can achieve when displacing. Both are given in a grid format obtained at the Warfare Games Center [6].

The combat-power projection model of a troop on the terrain is the integration of a height map model, specifically a line-of-sight model [4], and conceptual theoretical model developed based on Lanchester's differential equations and models for computing their indices [3].

When the combat-power projection and the trafficability images are integrated, we have the final cost image, where the shortest-path computations will be performed [5].

Heights-Map and Visibility Models

The height map is a Digital Elevation Model (DEM) whose elements represent the values of the level curves in the topographic maps used. This model is used to define distances more precisely and to define the influence areas of the combat-power projection of a troop on the terrain.

Distances are corrected by computing the terrain's declivity, that is, the distance between two points is computed on the plane and then corrected according to the height differences between them.

For the combat-power projection of a troop, we use visibility algorithms to determine whether a troop has observance over a given point (actually region, as we deal with cells with predefined dimensions). If such a line-of-sight exists, then the power projection of the troop on that region of the terrain may occur.

Trafficability Model

The trafficability map is a "thematic map" that represents the possibility of a troop of a certain nature (Infantry, Artillery, etc.) to traverse a given region.

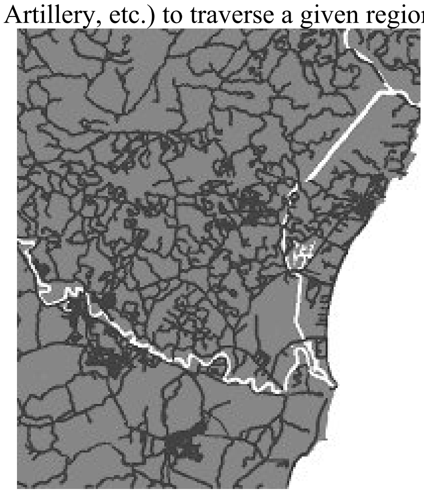

Figure 1. Image of a trafficability map of the Itaoca, ES region for troops on foot during the day with dry weather. Darker colors represent lower costs (roads). The white color represents an untraversable region (the sea and some rivers).

In the case of the digital model of the trafficability map used by Warfare Games Center, which serves as the basis for the development of this work, not only the traffic possibility is represented, but also the maximum speed that can be achieved.

To elaborate this map, one must have the terrain digitalization and river, heights, vegetation, soil and road attributes. With such terrain data, the maximum speeds of each kind of troop are computed, also considering light and weather conditions (day, night, dry or rainy weather), showed in Figure 1.

The specific troop speed will be computed over the trafficability map. In the case of this work, we are dealing only with the nature of the troop and with predefined light and weather conditions.

Combat-Power Projection Model

The theoretical model used to represent the combat power projected by a troop is a result of studies made based on the models used for computing losses in simulations made at the Warfare Games Center, on documents used by the Marines Corps to evaluate their field exercises, on works developed by T.N. Dupuy, and on models developed for other war games.

This model refers to the combat-power projection of infantry weapons, and computes the values based on the following parameters:

- Amount and range of the weapons;
- Lethality of the ammunition of each weapon;
- Cadence factor for each weapon, considering:
  - Distance between the weapon and the enemy
  - Maximum cadence of the weapon
- Approach factor – incidence angle of the enemy over the front of the troop.

The unit used to represent such indices is:

$$\frac{amount\ of\ shots \times probability\ of\ cause\ losses}{time\ unit}$$

We will not present the development of the computations for each of these parameters, as it is outside the scope of the present work. These values will only be computed for the regions where there is line-of-sight between the weapon and the power-projection location. We then obtain an image of the region where a troop projects power by influence of its weaponry.

In Figure 2, we can see the influence area of a section of machine guns. The lighter area in the middle of the big white circle is the region with the greatest projected power. The farther the distance from the white triangle, the darker the projection (less power). The areas marked with a small white circle/ellipse are those where the weaponry has no line-of-sight due to the relief. We can compare the implemented model with reality by observing Figures 2 and Figure 3.

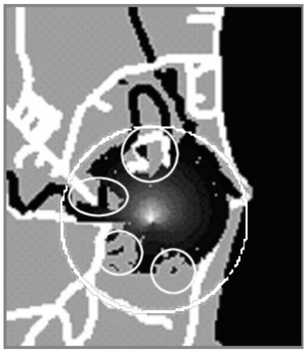

Figure 2. Image of the combat-power projection of a section of machine guns considering the relief (Itaoca, ES). The brighter white point represents the position of the section of machine guns aimed to up. The small white marks represent the regions where the direct fire weaponry cannot reach the target.

Figure 3. The white triangle represents the position of the section of machine guns. The white marks represent the regions where the direct fire weaponry cannot reach the target due to the relief at Itaoca, ES.

Integration of the Trafficability Model with the Combat-Power Projection Model

After the trafficability and the combat-power projection models have been defined, we will integrate these two images (matrices) to allow the use of a shortest-path algorithm.

The shortest-path algorithms considered work with only one parameter. As seen in previous section, we have a trafficability map whose parameter is maximum speed. Since we seek to minimize them, we must work with the inverse of speed, which is the time unit divided by the distance unit.

Special treatment is given to cases in which the speed is zero: these are regions that troops cannot traverse. To avoid dividing by zero, we attribute the maximum scale value to these cells.

In this case (combat-power projection), there is no need to treat the data, since the unit fulfills the idea of shortest path – the smaller, the better.

There is yet one scale to define. Taking into account computational effort and memory needs for processing the information, we chose the scale from 0 to 255 (1 byte) both for the trafficability and for the combat-power projection images. Therefore, the greatest value found in the image is identified, and all other values are divided by it. At the end, every value is multiplied by 255. We are making a linear reduction for a scale from 0 to 255.

This scale definition will allow us to make a weighed computation of the terrain influence (time required for the itinerary) or of the amount of losses from the shortest-path computation. When computing the shortest path, if one wishes the arrival time to the final point to have more emphasis than the amount of losses, we can attribute weight 2 to the terrain cost and weight 1 to the combat-power projection cost:

$$\frac{2 \times trafficability + combat\ \ power}{3}$$

This weighed mean can be dealt with according to the need of the user making the computations.

It is interesting to note that the dimensions of the measures are not being taken into account in the resulting image. What is important is to maintain the differences between the values, which occurs when a linear reduction is made to the desired scale. For instance, if a road has trafficability conditions much greater than displacement through fields, this difference is maintained. Similarly, a region that cannot be traversed must have a much greater cost than any other region. This image will not be used in the minimum time or in the losses computations, which employ the original trafficability and combat power images.

COMPUTATION OF THE PATH WITH SMALLEST COST

There are several solutions, algebraic and algorithmic, developed to compute the path with smallest cost between points. For the present work, some specific characteristics lead us to employ the Dijkstra algorithm as the basis for developing the desired algorithm.

Dijkstra Algorithm

The Dijkstra algorithm was chosen because leads to a fast solution and allowing its use with image models, since there are documented computational implementation techniques.

Two solutions were implemented: one based on dynamic programming and one based on the Dijkstra algorithm. For each solution, at least two different techniques were used. The implementation that better served the purpose of this work was the solution employing the Dijkstra algorithm using linked lists.

Among the most important characteristics, we can observe that:

- This algorithm is very fast for points with distances of up to 80 cells;
- The distances considered in our work are seldom greater than 80 cells;
- Up to around 150 cells between points (in the terrain model used), the Dijkstra algorithm was the

fastest solution. We must note that the efficiency may change according to the size of the image being treated. The parameters used were the ones with which we intend to work;

- With distances grater than 150 cells, the Dijkstra algorithm becomes slow; however, the need to work with such distances is very rare.

Cost Variation in the Image

The contact (attrition) computations are base on Lanchester's model for a differential equation system. To apply this model, one must have the value of the indices in Lanchester's equations, which can decisively affect the outcome of the battle. The range of the weapons, their lethality index, and their cadence and approach factor are the main aspects considered in the computation of such indices. They can vary according to the relative position of the forces and the amount of used ammunition and lost weaponry.

As the attacking troop advances, it causes losses to the defendant and also has losses. With the losses inflicted on the defendant, the whole combat-power projection made on the influence area is altered, thus generating the need for re-computing the entire combat-power projection matrix, and consequently the final cost matrix.

The equation indices are also altered at each step (cell) of attacker's displacement, as the relative position between the troops, the range of the weapons and their cadence factor also change.

As the indices change, the loss indices also change, which on their turn affect the combat-power image, which alters the total cost image, which on its turn will affect the shortest path, which alters the equation indices. The cycle is defined.

This cycle will remain active until the final point is reached or until the dislocating troop moves out of the influence area of the standing troop.

Time Computation

The differential equation system modeled by Lanchester has contact time, as one of its most important variables.

The displacement time can be easily computed, since we know the speed of the dislocating element and the distance it has displaced. However, during engagement, this displacement speed changes. This issue must be considered for computing the losses index, as the variation of the permanence time in certain contact conditions may cause considerable differences in the results of such index.

The model used to define speeds during engagement is based on war game models, in which speed varies according to the ratio between the combat powers of the progressing troop and the defending troop. The greater this ratio, the faster the speed of the progressing troop. If this ratio is smaller than 1 – that is, if the defending troop is stronger than the displacing troop – then the displacing troop will have stopped (speed is zero).

Shortest-Path Computation with the Dynamic Image

We have defined a step as the amount of cells traversed until the reevaluation of the image costs is made. A step can vary and be adjusted by the user. The larger the step, the more imprecise and fast the computations will be; the smaller the step, the more precise and slow they will be.

A step is defined in terms of cells, because, depending on the direction taken by a moving troop and on the area's trafficability value, distance and time may be variable, which would require computing the shortest path in cell fractions and greatly increase the complexity of the process. In the defined algorithm, the computations will have as the minimum parameter the distance from the center of a cell to the center of its neighboring cell.

The steps are the following:

1. Initialization: defines the initial point, attributing it value "zero"; defines the destination; defines the infinite value for all arcs (time/distance from the center of a cell to the center of its neighboring cell);
2. The initial point is closed and the cost of the neighbors is updated – to close a point means to define the open neighbor (a neighbor that is not closed) that has the smallest cost to the initial point;
3. Dislocation to the neighboring node with the smallest cost, now current node (the next node to be closed) – it is interesting to note that there is an ordering requirement to define the node with the smallest cost among those that are open;
4. Comparison of the costs of each open neighboring node with the sum of the arc that connects them to the current node and the cost of the current node; if one of these costs is smaller than the current cost, the cost of the open neighbor is updated;
5. The current node is closed;
6. Steps (3), (4) and (5) are repeated until the destination point is closed;
7. After the destination point is closed, a path is defined from the destination point to the initial point, marking the nodes that pass through a region over which the enemy projects power;
8. In this inverse path, the last node is marked (which is the first one in the origin-destination direction);
9. Going back to the destination point, it is added to the value of the step to define the portion of the path that will be evaluated;
10. The indices of Lanchester's equations are defined, which are the combat power ratios;
11. The necessary time to traverse the specified path is computed considering the speed according to combat power ratio;

12. With time and the computed indices, the losses indices of both sides are defined and applied;
13. The combat-power and total-cost images are recomputed;
14. Return to step (1); the initial point now considered is marked plus step, and the process is repeated until the destination point is reached.

After the losses indices are applied to attacking and defending troops, there is the possibility that one of the troops reaches a number of soldiers that is incompatible with the continuation of its activities. This fact will cause a decrease in the combat-power projection of a troop over its enemy, or even, for the attacking troop, the interruption of its progression.

ANALYSIS OF THE OBTAINED RESULTS

Simplification of the Models

The presented models, though theoretical, contain several simplifications that can influence the results:

- The troops are considered as punctual objects, when they actually spread over the terrain, occupying areas. This approximation will influence the computation of the distances traversed and of the engagements;
- Time and distance computations are made between neighboring cells; therefore directions with angles different from multiples of 45 degrees are formed by composing angles which are multiple of 45 degrees. This generates a difference between the distances measured directly between two points and the ones computed in the shortest-path itinerary. We cannot measure such difference nor compare it to the actual displacement of a troop over a terrain because no data is available on the difference between the displacement carried out by a troop attempting to move in a straight line between two points and the actual distance between such two points;
- For distance computations, Earth curvature is not considered;
- Since the trafficability map presents the maximum speed for each cell, there is no speed variation according to the different types of vegetation, soil and declivity;
- In the computation of the influence areas of a troop's combat power, the trajectory of the weapons' projectiles is considered as a straight line;
- In the computation of troop losses, the possibility of interruption or the will of the troop to execute the engagement are not considered. When a troop enters the enemy troop's influence area, it automatically starts to cause and suffer losses;
- The defending troops cannot change their position during the computations;
- A troop is considered to remain firing until its last individual or ammunition is extinguished, if there is still an enemy in its influence area.

Results Obtained

We now present the results of the simulations performed:

Case 1:

A company (top asterisk) with 187 soldiers attacks a squad with 43 soldiers and a section of machine guns with 9 soldiers (bottom asterisk). The step used is 1 traversed cell for each recalculation of the shortest path. The weight of the combat power is 10 times greater than the weight of the terrain.

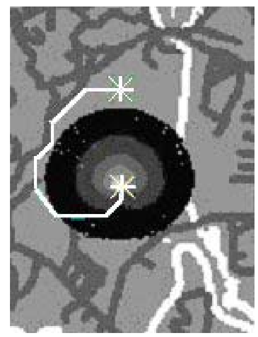

Figure 4. Result of the shortest-path computation. The company has traversed a distance of 6061 meters in 2 hours, at an average speed of 3024 meters/hour.

Analyzing Figure 4, we can see that the path chosen went through the flank/rearguard of the squad and the machine-gun section, avoiding a frontal combat, where the power projection of the defending troops is greater.

From the total initial enemy soldiers of 52, only 2 remained. The losses were 6 soldiers in the company and 50 in the defense. These values are justified by the power-projection model used, which takes into account the approach factor, and by Lanchester's differential equations.

Finally, we can see that, even though the image of the combat-power cost has weight 10, while the terrain cost has weight 1, this does not mean that terrain characteristics were lost, despite being almost imperceptible to the viewer. The shortest path passes through the closest road to move around the influence area of the defending troops.

Case 2:

The same troops, step and positions presented in the Case 1 are being considered. The main difference now is that the terrain is given a weight equivalent to that of the combat-power projection.

From the total initial enemy soldiers of 52, 3 remained. The losses were 23 officers in the company and 49 in the defense. Comparing these results with the previous case, we see that, when a greater weight is given to the enemy's combat power, it means we should look for the path that will cause fewer losses for the attacking troop over a shorter time to reach the destination.

This can be verified in the results obtained: in Case 1, the company lost only 3 soldiers, while in Case 2 it lost 23. On the other hand, it took virtually twice the time to reach the target: in Case 1, it took 2 hours, while in Case 2 it took 1 hour 02 minutes.

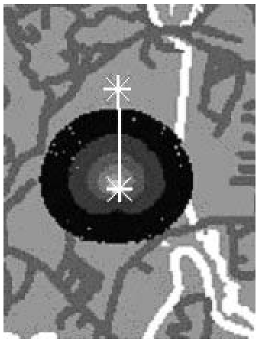

Figure 5. Result of the shortest-path computation. 2171 meters were traversed in 1 hour 02 minutes, at an average speed of 2110 meters/hour due friction with the enemy.

Case 3:

This case presents the shortest path computed to connect two points without the presence of an enemy troop.

Since, as we can see in Figure 6, there is no enemy troop between the initial point (right asterisk) and the destination point (left asterisk), the computation was made only based on the terrain, defining the path that would take the shortest time between the two points.

The results obtained were: traversed distance of 12706 meters, time of 3 hours 23 minutes, at an average speed of 3750 meters/hour.

This case shows that, even though the algorithm was developed for computing the shortest path with dynamic-cost matrices, it can also be used for images with static values.

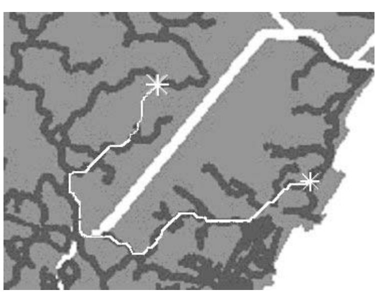

Figure 6. Computed path between two points with no enemy troop.

CONCLUSIONS

Input data, trafficability map, lethality indices and model parameters are essential for the results to reflect reality. Since the presented data were not obtained from statistical evaluation analyses, the results of the developed algorithm are useful only for test purposes for the theoretical model elaborated.

The developed algorithm proved to be very flexible, allowing adjustments in terms of the precision of the results to be obtained and of the necessary time for the solution. It can also be used as any other algorithm for shortest-path computation in an image.

This model allows military analyses of time, distance and losses to support the decision-making process. Even though the results cannot be considered in absolute terms, a comparison between the proportions of the efforts in two possible solutions could be useful.

This work exposes the need to study the operative efficiency of a troop in order to allow the employment of an efficient tool to evaluate losses in a military operation. The interface of the program is showed in Figure 7.

Finally, we have reached our purpose of quantifying contact between troops in terms of time and losses, taking into account terrain variables, and our model can support the analysis stage in the MPP system.

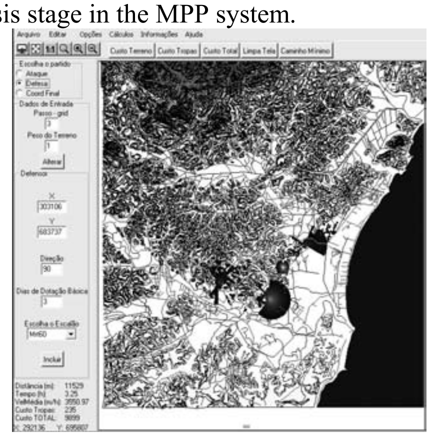

Figure 7. The interface of the decision making tool to military planning process.

References

[1] Ancker, C. J. Jr., and Gafarian, A.V., “Modern Combat Models: A Critique of their Foundations”, Operations Research Society of America, USA, 1992.

[2] Jaiswal, N.K., “Military Operations Research Quantitative Decision Making”, Kluwer Academic Publishers, Massachusetts, USA, 1994.

[3] Coutinho, Lazaro., “Sobre a Teoria do Combate de Lanchester”, Monografia de Mestrado em Matemática, Universidade Federal Fluminense, Brasil, 1982.

[4] Seixas, R.B.; Mediano, M.; Gattass, M., “Efficient Line-of-Sight Algorithms for Real Terrain Data”, III Simpósio de Pesquisa Operacional e IV Simpósio de Logística da Marinha - SPOLM'99, Brasil, 1999.

[5] Seixas, R.B.; Sá, A. M.; Lauro, A.; “Modelagem de Ferramenta de Apoio a Decisão Baseada em Grafos” , IV Simpósio de Pesquisa Operacional e V Simpósio de Logística da Marinha - SPOLM, 2001.

[6] SJD-2; “Sistema de Jogos Didáticos”; Centro de Jogos Didáticos do Centro de Instrução Alte. Sylvio de Camargo; Marinha do Brasil, Brasil, 2000.