AN ANALYSIS OF OPTIMUM ROUTES OF APPROACH (RA) THROUGH GIS MODELING

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ABSTRACT

This paper describes the processes and results of Routes of Approach (RAs) modeling using GIS which can be used in analyzing anticipated hostile threats. The RA modeling implemented within GIS is known as IPB (Intelligence Preparation of Battlefield). This model represents a classical terrain analysis application for which GIS technique has been adopted. The model makes a priority table for the candidate RAs by considering factors of RA and corresponding weights for each factor. Many advanced countries have been using GIS which can manipulate data collection, update, analysis, and display in RA analysis. Our military forces, having relatively less experience in computerized analysis, recently found its importance and started developing RA analysis system. Thus, the objective of this study is to develope a scientific RA analysis system which can combine GIS, image processing, and terrain analysis methods to support field commanders who have to set up strategic tactics in battlefield operation.

INTRODUCTION

The RA modeling was developed in 1993 as a scientific terrain analysis system for the battlefield operation using GIS techniques such as precision registration, overlay, on-line editing, etc. It synthesizes and analyzes various information on the enemy forces, and can judge and prepare the countermeasure in case of an enemy's hostile action. Rapid and accurate terrain analysis reduces uncertainties in mobility, firing, and communication and guarantees efficiencies in combat capability as well as weapon system. It also enables easy planning and prompt decision in operation field, and thus serves as the critical factors in battle operations. The main goal of developing this modeling is to complement the conventional qualitative method evaluated by human eyes, and to produce an objective and quantitative methodology.

This paper describes the process of obtaining, inputting, and analyzing accurate data for battlefield operation. To analyze the battlefield information, we should select several candidates for RAs and evaluate corresponding factors for each RA. For each factor, it is necessary to prepare the accurate GIS data layers. The RA modeling simulation system has been implemented as an interactive tool, allowing changes to be quickly entered into the decision-making process. This study shows how to prepare a data base for each of the six factors used for RA analysis. The results of this paper also suggest possible improvements for the future studies.

PROCESSING FLOW OF RA ANALYSIS

The RA analysis procedure is composed of the evaluation of threats, the analysis of the regions of interest and influence, the analysis of the terrain, and the synthesis of threats. We should prepare the GIS data layers such as slope gradient, slope aspect, woods, soil, land cover, major rivers and major terrain & feature (e.g., target area or object, high ground, communication center, terrain suited for the installing headquarters, etc). These are integrated to the six factors such as observation/line-of-fire, covered/concealed area, obstacles, major terrain&feature, mobile space, and easiness of troop disposition, which will be evaluated using GIS techniques and be entered as input data of the modeling. The RA rating is computed as the summation of each input factor times its weight. With quantitative results generated by the RA analysis, the intelligence staff analyzes the situation and makes a final decision through the RA modeling simulation.. The detailed process is as shown in Figure 1.

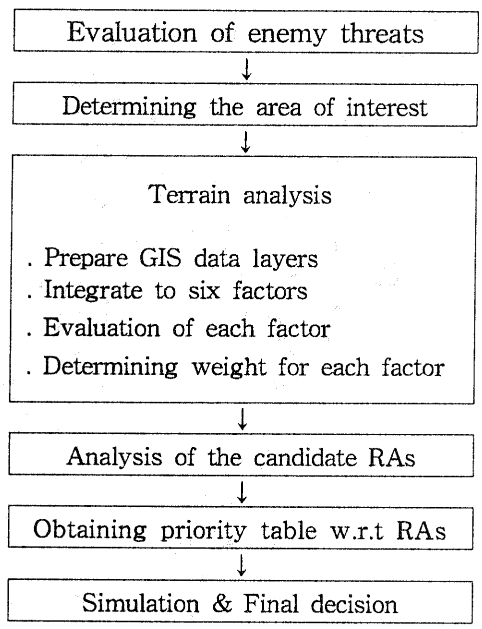

Figure 1. Processing flow of RA modeling

The RA modeling assigns a rating to each factor, in a scale of 1 to 100, based on functional curves. Each rating is then scaled by a weighting value, and the weighted ratings are summed to obtain the priority for the each RA. The usefulness of the priority number comes into play when comparing two or more RAs. The RA with the highest priority can be considered the most possible invasion RA, and therefore the RA modeling becomes a useful tool in predicting and preparing for threats of hostile forces. The priority of each candidate RA can be obtained by the following algebra.

$$RA_j = \sum_{j=0}^{5}(W_j \times F_j)$$

where RA_j = each RA
W_j = weight for factor j
F_j = factor j

The weight value for each evaluation factor can be determined by the Delphi method(ATTAS, 1993) with advices of military experts. The weight values are heavily dependent on the field mobile capacity and on the type of military units (infantry or mechanized), and thus the process of deriving weight values is very important. In this case, the expertise of experienced military experts and/or terrain analyst can be valuable source of information.

Maps of the RA modeling are designed to be screening-level tools. The present study takes a GIS approach to derive the above RA modeling map. Each of the six factors is represented by data layers in GIS, so changes to the final map can be made simply by modifying factor values in the appropriate data layers and by re-running the calculation algorithms. The GIS analyzing algorithms for the multi-layered data such as digital elevation model (DEM), soil, land cover, slope gradient, slope aspect, etc. have been implemented. These algorithms include weighted boolean arithmetic, spatial interpolation, polygonal operation, and user defined functions(Laurini, 1992). However, this method greatly depends on the preparation of accurate GIS data and on the setting of weights by military experts and terrain analyst. Additionally the artificial intelligence techniques such as knowledge-based processing and expert system are required.

The study uses the IPB which has been developed to provide military officers with terrain information necessary for efficient battlefield operation and troop movements. Thus, the system puts great emphasis on user interface for military officers to be used easily.

DATA LAYERS

The terrain analysis is performed to derive the necessary GIS data layers for the RA selection and evaluation. It contains the calculation of covered/concealed area, slope gradient, contour, elevation, and mobility. We use DEM, soil, land cover, slope gradient, slope aspect, etc. as input data for analyzing algorithms. We briefly explain the above data layers in the following and display corresponding images in Figure 2.

Covered area

Covered area is rated by three degrees of "good", "normal" and "bad" considering slope gradient, land cover, etc. and used it when evaluating terrain in an operation field.

Concealed area

Concealed area is rated by the aerial observation in operation field considering the land cover.

Slope gradient

The slope gradient is calculated by the degree of slope distribution in an operation field. It is used in estimating mobile routes, development of roads, and selection of communication sites. Slope rates is taken as the maximum value among the 8 direction gradients in 3 x 3 windows.

Atmospheric phenomena

Atmospheric phenomena is a critical factor which restricts preparing an operation and making a plan in the battlefield. In the present study, we simplify the time-varying change of atmospheric phenomena once a day and collect respective representative value, to establish them as a database. The observed and reported atmospheric phenomena are classified as temperature, precipitation, humidity, wind, and fog.

Field mobility

After analyzing the field mobility for mobile weapon considering slope gradient, slope aspect, land cover, and soil simultaneously, we use the results in making a operation plan and combat capability. The analysis logics which was developed by the Korean Army Headquarters not only uses special map for terrain analysis, but calculates slope gradient, slope aspect, etc using accurate digital data. Thus, it guarantees more elaborate results than any other previous algorithms.

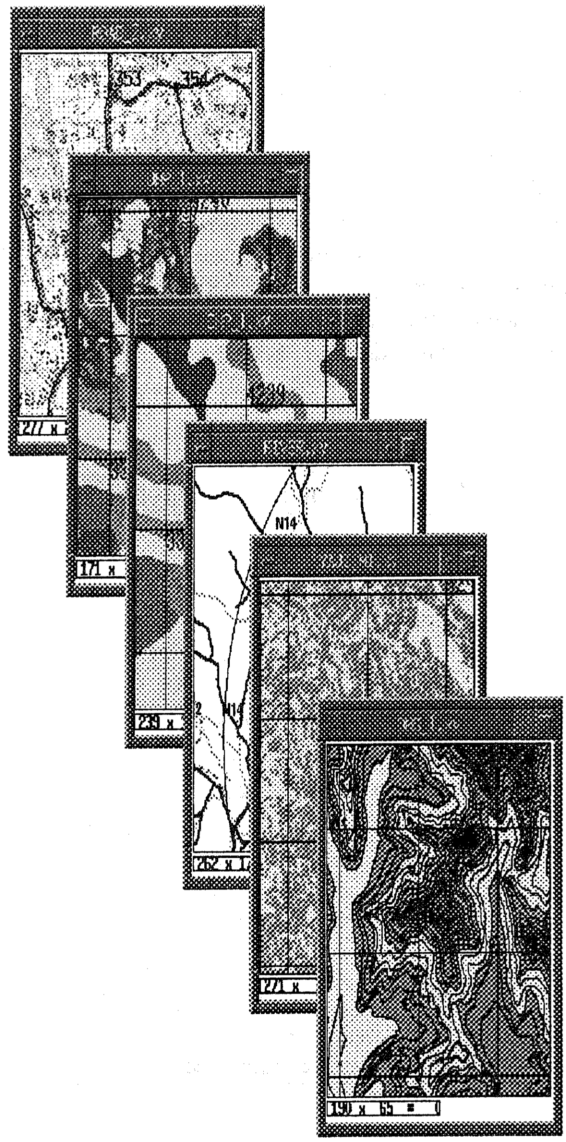

Figure 2. GIS data layers for the RA selection and evaluation. (a) network of major roads (b) covered area (c) concealed area (d) major rivers (e) mobile space (f) slope gradient

CONSIDERATION FACTORS

To analyze and evaluate an RA, following six factors are computed and weighted integrating input data layers described above.

Observation/Field of fire

Each candidate RA modeling is divided into subsections with a uniform length of 1 km from the start point to the final destination and the observation line is determined for each of subsections. Additionally, we developed the more realistic and accurate two-dimensional(2D) computational method which calculates observation/field-of-fire considering human's visible angle. Since men are the subject of observation, it is desirable to include the characterists of the human's vision system in analysing visible lines. In the previous method, we set a visible line perpendicular to the base line of the observer and calculate visibility in one dimensional direction. In this method, we are able to obtain more realistic and accurate line-of-sight data implementing 2D fan-shape analysis algorithm which conforms the human's instant visible habit. Thus evaluation mark(EM) can be computed with equation(1).

$$EM = \frac{\text{area of observation or field of fire}}{\text{area of RA}} \quad (1)$$

Covered/Concealed area

Average rate of covered/concealed area for each candidate RA is computed.

Obstacle

The immobile area is computed by analyzing the slope, land cover, soil, and drainage factors.

$$EC = \frac{\text{area where movements are impossible}}{\text{area of RA}} \times 100 \quad (2)$$

Since the effect of obstacles is inversely proportional to the mobility, EM for the obstacles is taken as the inverse of the evaluation criterion(EC).

$$EM = \frac{1}{EC} \quad (3)$$

Major Terrain&Feature

The number of major terrain&feature included in each of RA is counted and EM can be computed with the following equation.

$$EM = \frac{\text{the number of major terrain or features included in RA}}{\text{total number of major terrain features}} \times 100 \quad (4)$$

Mobile Spaces

The area of mobile space for the mechanized unit and the infantry unit for each RA is computed. For the mechanized unit, mobile area can be calculated by analyzing the field mobile capacity of mechanized equipment. For the infantry unit, the slope and drainage factors are taken into account. The EM for mobile space can be computed as follows.

$$\text{effective width of mobile space} = \frac{\text{area of mobile space}}{\text{length of RA}} \quad (5)$$

$$EM = \frac{\text{effective width of mobile space}}{\text{max imum width of RA required for tmovement}} \times 100 \quad (6)$$

Easiness of Movements

The network of roads, slope, and the length and direction of the RA are taken into consideration to compute the easiness of movements.

$$\text{EM for network of roads} = \frac{\text{total length of roads}}{\text{area of RA}} \times 100 \quad (7)$$

$$\text{EM for slope} = 100 - \text{average slope of corresponding RA} \quad (8)$$

$$\text{EM for length of RA} = \frac{1}{\text{length of RA in center line}} \times 100 \quad (9)$$

$$\text{EM for direction of RA} = \frac{\text{the area of the enemy}}{\text{total area RA}} \times 2 \times 100 \quad (10)$$

SIMULATION

The RA modeling simulation system has been implemented as an interactive tool, allowing changes to be quickly entered into the decision making process. Thus EMs are computed for each of evaluation factors and summed-up table is presented on the top of the topo map or satellite image. Troop mobility map is overlaid on the top of the digitized topo map, and the several candidate RAs are selected and drawn on the screen in the elongated polygon form in figure 3. The results of this modeling matches that of manual analysis very well for the 30km x 30km test area. as shown in Table 1.

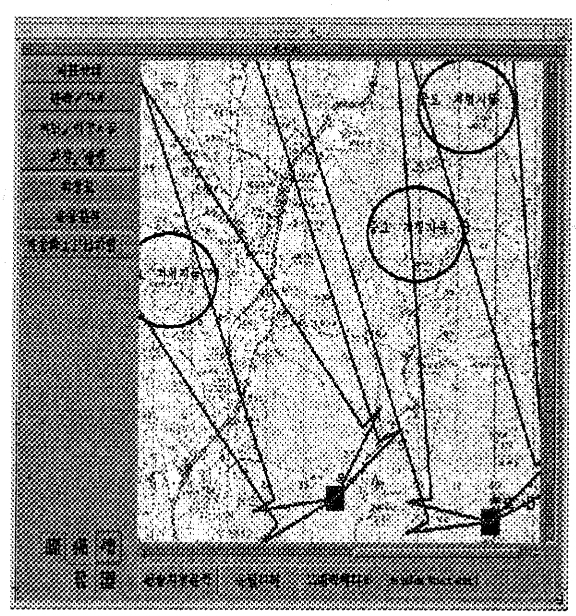

Figure 3. four candidate RAs are selected and displayed on the top of the topo map.

Consideration factors	Weight	RA			
		A	B	C	D
Observation / line of fire	0.1400	13.1	14.0	12.0	13.5
Covered / Concealed area	0.1400	12.8	14.0	9.44	12.2
Obstacles	0.1500	13.3	15.0	8.94	9.43
Major terrain & features	0.1800	12.0	6.00	18.0	12.0
Mobile Space	0.1900	19.0	17.3	11.7	12.0
Easiness of troop disposition	0.2000	20.0	17.7	15.8	15.0
Total(Score)		90.4	84.0	76.0	74.3
Exit	**Priority**	1	2	3	4

Table 1. Priority table for simulation in Figure 3

DISCUSSION

This method greatly depends on how objectively military experts and terrain analysts prepare accurate GIS data and set weights for six factors. Usually it is not easy to prepare the accurate terrain data in time on the anticipated operation field in various situations. However, this problem can be somehow overcome by using GIS technologies (ERDAS, 1990; ESRI, 1990).

The integration techniques of remotely-sensed image and GIS procedures such as precision registration, overlay, and online editing techniques have been developed and utilized in the study (Yang, 1989a; 1989b). Additionally the simulation results can be significantly varied if consideration factors and the corresponding weight values change. The advice and consult from the experts can be helpful. However, the artificial intelligence techniques such as knowledge-based processing and expert system are required.

CONCLUSION

The RA modeling has been developed to synthesize and analyze the enemy, terrain, and weather in the battlefield. This RA analysis technique is expected to reduce the uncertainty in troop maneuvering, fire planning, and communication site selection. The accurate information produced by the RA modeling will be able to enhance the combat capability of a military unit and the efficiency of weapon system and also support military officers to make a prompt decision and operation plan. Thus this modeling provides a tool for the field officers who select the candidate RA of enemy troop and who evaluate the strong and weak points of each RA.

This modeling makes a table as a final results which is generated by evaluating the six factors, one for each layer, derived in the previous sections.

This modeling is equipped with 2D and 3D graphic tools(O'Reilly, 1990.) as well as images and GIS data processing tools such as precision registration, overlay, online editing, etc. The test area of 30km x 30km is selected and entire process of RA modeling have been performed. The results of simulation match that of manual analysis very well. More research is required to adopt AI techniques such as knowledge based processing and expert system to obtain weight values for consideration factors.

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