Developing military situation picture by spatial analysis and visualization

Matti Janlöv, Tiia Salonen, Hannes Seppänen and Kirsi Virrantaus

Helsinki University of Technology,
Department of Surveying, Cartography and Geoinformatics
PO Box 1200, FIN-02015 HUT, Finland
matti.janlov@tkk.fi, tiia.salonen@hut.fi,
hannes.seppanen@tkk.fi, kirsi.virrantaus@hut.fi

Abstract. Terrain information and the knowledge derived from it are in important role in military situation awareness and the so-called situation picture. This article describes how geographic information, spatial analysis and visualization methods can be used in the specific military application. As the theoretical framework the OODA –loop has been used and we have shown how data is developed into information and knowledge and finally used in the decision phase. The project is funded by the Finnish Defence Forces and the motivation for this kind of research from FDF side is the situation in which all information systems are redefined and also a new platform for GIS-applications is taken into use. The research questions for us come from the efficiency of algorithms and usability of information as well as the requirements of fast and correct understanding of visualized information.

1 Introduction

Terrain information and the knowledge derived from that are in important role in military situation awareness and the military situation picture. Situation picture is a collection of maps and analysis results describing the terrain; essential part of the situation picture is made of the tactic symbols describing the own and enemy troops in the battlefield. The scale of the situation picture depends on the users and it can be anything from large to very small. Situation picture is the main tool for the commander.

Situation picture can be developed into a GIS-application. In this project the goal was to develop spatial algorithms and visualization techniques to support efficient use of topographic information in a situation picture application. The project was a preliminary study that will later on be used in defining the users requirements of the developed new system. The Finnish Defence Forces financed the project and the first part of the work was done at the Helsinki University of Technology during the year 2004. The work will continue during 2005 and an experimental prototype will be implemented in ESRIs ArcEngine environment.

The theoretic framework for the development is the so-called OODA –loop. OODA comes from the words observe, orient, decide, act (developed by Boyd) and it describes the different stages in decision-making. In our application the loop starts with data collected by intelligence, surveillance, target acquisition and reconnaissance (observe). The raw data is then processed and organized into the database (orient) and used in decision making together with existing terrain data (decide). Data become into information when the user combines it with the contents of database. Information becomes into knowledge when the user interprets the information according to his/her own needs. The final stage of the loop is to act, which is our application means commands. In this described loop the efficiency and correctness of the decision-making is most important. The hypothesis of this research is that this decision-making could be supported the use of spatial analyses and visualizations.

The project included three diploma theses projects by Mr. Hannes Seppänen, Mr. Matti Janlöv and Ms. Tiia Salonen. The work was instructed by Major Juhana Nenonen and supervised by Professor Kirsi Virrantaus. The following chapters are written by the authors mentioned. Material, methods and results are also described in separate chapters.

2 Automation of data collection for the situation picture by using geographical information and analyses

This part of the paper is based on Master's Thesis by Seppänen (2005).

2.1 The problem given and the objectives

A lot of research has been made at Finnish Defence Forces concerning e.g. sensor techniques and informative use of colors. However no such application has been made that could find out the correctness of an enemy observation based on information available about the terrain. The objective of this part of the research is to find out the reliability of the incoming data using geographical information and GIS-analyses.

2.2 Role and content of situation picture

The purpose of situation picture is to allocate resources in an optimal manner to gain advantage and minimize losses. It can be used for estimation and prediction of enemy movements, groupings and strategy compared to own. The collection of data cannot be any faster it's now because it is now almost real-time. The speeding up of situation pictures formation has to be made by fastening the processing, analysis and distribution of knowledge. (STAE 2004). Ahvenainen has added these to the so-called OODA-loop, Figure 1, presented by John Boyd (Piiroinen 2003).

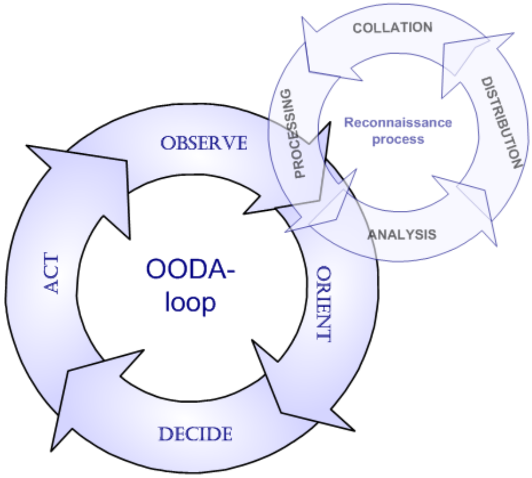

Fig. 1. OODA-loop and reconnaissance process (Piiroinen 2003)

Figure 2 illustrates the process before an observation is added to the situation picture database and how this process was described in this research. The process begins when an enemy observation is made and message including its facts is sent. To check observations reliability, analyses on its location and visibility are made. After it has passed these analyses, observation is added to the database with metadata concerning its reliability.

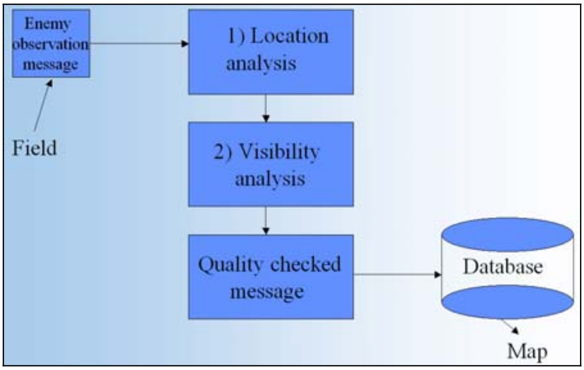

Fig. 2. The process of the analysis of the quality.

2.3 Analysing the reliability

The purpose of these automated analyses is to analyze the reliability of the observation and to remove possible human errors like misspelling of coordinates. It is certain that something has been seen but observations reported location could be illogical in respect of terrain and circumstances.

Location analysis

The first automated analysis examines the location of the observation based on the knowledge given in the received message and comparing it to the terrain data available. For example this analysis could reveal an unlikely situation in which a tank is observed in a lake in the middle of the summer. This observation is most probably not correct and needs to be checked. As a result from the analysis we receive an estimate of observations quality. Location analysis uses so called cross-country mobility dataset (CCM) to examine the reliability of the observations location. This dataset is in raster format and it describes the easiness of mobility in given terrain. It is calculated for number of vehicles and its pixel size is 25x25 meters. Using this dataset we can estimate also the potential positions for observations location in the surroundings. Figure 3 represents the result of this analysis. In the center is the observation surrounded by a part of the result of CCM. In the picture green (7, Go) represents best mobility and grey/blue (1/0, NoGo) worst mobility.

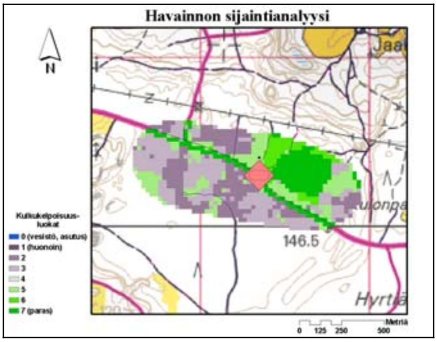

Fig. 3. The location of the observation together with a piece of cross-country mobility layer.

Visibility analysis

Visibility analysis is done after location analysis is completed. This examines the relation between observer and observation. It is quite difficult for the observer to estimate locations, especially distances. Using this analysis we can estimate how logical the relation is e.g. could the observation have seen from the observer's location. Visibility analysis is a basic GIS analysis but usually it takes into account only the elevation model, Figure 4. However vegetation has enormous effect on visibility especially in Finnish landscape. In the literature very few approaches can be found. In this research some new methods were developed. In the following a brief description is given.

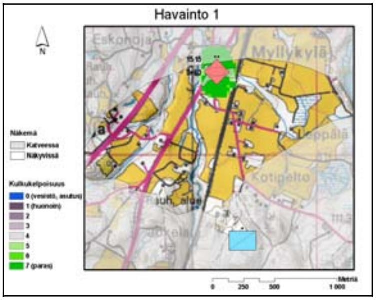

Fig. 4. Visibility analysis. The observation is inside the visibility area as well as located in a suitable terrain according to the cross-country analysis. This observation can be accepted to the database.

The simplest method is to calculate normal visibility and examine if the line of sight meets vegetation on its way and cumulatively shortening the visibility. This is very simple and not very accurate method. Other possibility is to make a new digital elevation model by using vegetation information and Monte Carlo simulation. The visibility is then calculated using normal visibility methods. Also an accurate but complicated version was mentioned where also e.g. the contrast of observation was also taken into account. There is also a possibility to visualize vegetation by using density maps so that the affect of vegetation can be estimated by visual interpretation.

Combining the results of the analyses

Location and visibility analyses produce raster layers, which are combined using simple map overlay. O'Sullivan and Unwin (2003) introduced this method and it can be done simply by adding matching map layers values. It can be done also using weighted linear combination where every criterion has certain weight. The layer produced describes the favorability of the location of the observation in any given point. If the location and visibility analysis layers don't match, message is sent back for a crosscheck.

2.4 Uncertainty

There is a lot of uncertainty mainly because of datasets and the nature of the things we are trying to model. First of all the most accurate datasets pixel size is 25x25 meters. Using this resolution we have to generalize quite a lot. Also the location of the observation isn't very accurate, we have to remember that it is done under pressure and possibly without any instruments. The purpose is to produce a suggestive result, not an accurate fact that you can completely rely on. Even more uncertainty involves into visibility analysis because of vegetation and its ever-changing nature. Despite of this uncertainty these analyses are useful if the user is aware about the quality of information. By representing the uncertainty together with the result of analysis the user can estimate and make his/her own decision about the reliability of the observations.

3 Predicting the movement of the enemy forces using topographic data

This part of the paper is based on Master's Thesis by Janlöv (2005) and uses the results from the previous chapter.

3.1 The problem given and the objectives

To optimize the use of the situation picture, further analysis can be made. One critical issue that persons in commanding position would need to know is an estimate of the coming troop movements. In the modern battle situation the technology and speed have made the importance of information about the combat scene, position of troops and conditions, that will say the situation picture in general, more crucial. Taken it to the edge, information is the key for winning a battle and the one that has superiority in information (Hyytiäinen, 2003) has a big advantage. (Nenonen, 2004).

This part of the paper deals mainly with the two last stages in the OODA-loop that will say the decision making and acting. In that sense this part is totally dependent on the first part of the loop concerning the situation picture. It will be shown that the prediction is made basically upon the observations made in the first stage and thereby it's of great importance that the information in the first part of the loop is correct, or in other words, more correct information gives more correct end result.

This paper focuses on the situation picture of the army, vehicles moving in terrain. Predicting the movement of the enemy is not a new phenomenon in its sense. It has been used for a long time especially in the air force and for airplanes. In this case it has to be remembered that space in the air is unlimited and the speed of the airplanes are very high. This means that a plane will keep the same speed and direction for a longer time but it is also limited by the physical laws that will say an airplane can't suddenly stop in the middle of the air and turn around. When looking at difficulties of predicting the movement of the land forces, or the army, several problems comes up. The way to move is different; a vehicle can stay for a longer time on the same place. It can turn in any direction without any problems and if it is a column it can split in several units. The terrain where the vehicles are moving is a limiting factor itself, and by taking that into account it can be used in the prediction. (Nenonen, 2004).

3.2 The process of prediction

The process of the prediction was outlined in this research. The process can be divided into several steps (Fig. 5). First the stored information of the observed targets is taken into account. The main problem is that the observations are from different moments of time and there can also be multiple observations of the same vehicle. In other words the mess needs to be cleaned up so that correct information can be derived. This is done mainly by predicting the present position of the vehicles and then generalize lower level objects, like platoon, into higher level objects, like companies. When this is done the actual prediction can be done, the prediction that is done from present and into the future. So far the only thing done is to order the information and get out what is relevant. Some possible methods, that can be used for the prediction is presented below. Only two of them where tested with real data and in a working GIS environment (ArcGIS 8.3). The result from the prediction, that will say the possible coming movement of the enemy troops, should only be used as a device to support the decision-making.

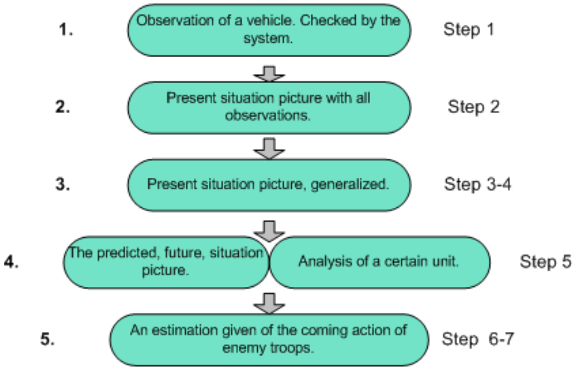

Fig. 5. The seven steps in the process of prediction, from observation in the terrain to the estimation of coming action.

3.3 Basic data used

Before going deeper into the different prediction methods, the factors used in the prediction will be shortly explained. The prediction is mainly done by using existing information. Two main sources are used, the first one is the information that can be derived from the situation picture, like the observation data, and the second one is different topographic databases. From the observations important data, like the speed, direction and type of vehicle, is used. Also the position of the observed vehicle and time of the observation are important factors. A lot of terrain information is available in the topographic databases (Hyytiäinen, 2003). The most important data set among others is the cross-country mobility layer (CCM layer created as a result in a military terrain analysis application) given in raster format and classified according to the principle 'Go-Slow-NoGo'. The CCM layer lacks important topographic information. This is corrected by adding information from other sources, like the Topographic Database (maintained by the National Land Survey, NLS), with data in vector format and military data, like minefields. (Fig. 6). This data could in the future be completed with weather information, when the weather condition affects the movement of a vehicle, like rain and fog.

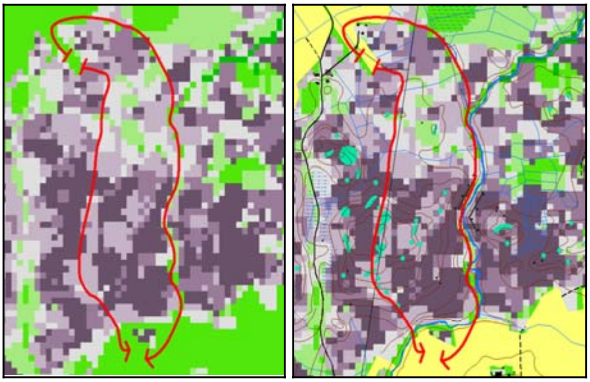

Fig. 6. The cross-country mobility layer to the left and to the right the CCM-layer with additional topographic data for improvement.

3.4 Methods for prediction

Simple prediction can be made using the data mentioned by calculating a new position for a given point in time. The assumption is that the moving vehicle mainly uses the 'Go' areas, and by identifying the routes that follows these areas, a prediction can be made upon them. When making a more accurate prediction more advanced methods would be used. By using the stored observations of the same vehicle, the 'historical' data, the pattern of movement or the main heading or direction for the vehicle could be decided. When knowing the main heading for a vehicle, it can also be used in the prediction, when assuming that the vehicle has a certain goal and not moving randomly around in the terrain.

Accessibility zones and route optimizing

Four different methods for prediction will be presented. These four can be divided into two groups, with two methods in each. In the first group there is the accessibility zones and route optimizing. These methods don't predict future positions for a vehicle, they only give a hint of possible choices for a vehicle to move, that will say the accessibility zones, using time contours, tells which areas a vehicle can reach in a certain time but don't tell exact position (Fig. 7). In route optimizing an end point needs to be given, and the end point is usually defined by the user and are thereby a subjective choice (Fig. 7). Then the optimal route for example according to time and cover is calculated, in other words the fastest route with the best cover for the troops is calculated as a line or corridor. A corridor is less exact and takes into account some uncertainty. (ArcGIS, 2002 and 2004).

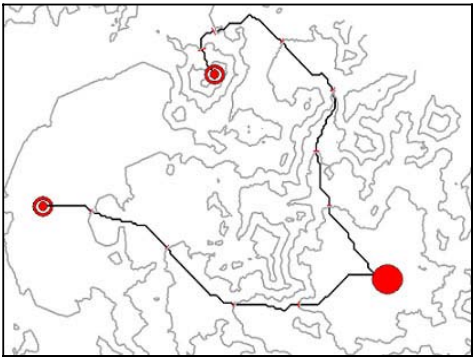

Fig. 7. Route optimizing and time contours. Starting point is the big red dot and the end points are the dots with a ring. For every contour passed five minutes has gone. The routes given are optimal according to time (fastest path).

Kalman-filter

The Kalman-filter is well known in navigation. Here only the idea of how to use the Kalman-filter in this particular prediction case will be shown. For the mathematics behind the filter, Strang and Borre (1997) give the basics. The main principle is that a prediction for an object is made and then corrected by a new observation of the object (Fig. 8, left). The Kalman-filter consists of two parts, the dynamic model and the observation model. The state vector describes completely the state of a dynamic system, in this case a moving vehicle, like position and velocity. The dynamic model describes the process of motion in time for the state vector, while the observation model describes the state vector at the time of observation. In this case the dynamic model is the terrain where the vehicle is moving and the observation model is the observations of the vehicle done by the reconnaissance that then are used for correction. The terrain/dynamic model could be described as a potential-surface (Fig. 4, right), where 'NoGo' has high potential and are thereby avoided and while 'Go' areas have lower potential and the vehicle is drawn to these. To avoid random movement the main heading, the direction where the vehicle is moving, could be described as a low potential-hole (Fig. 8, right). This hole can change if new observations show that the main heading is changing.

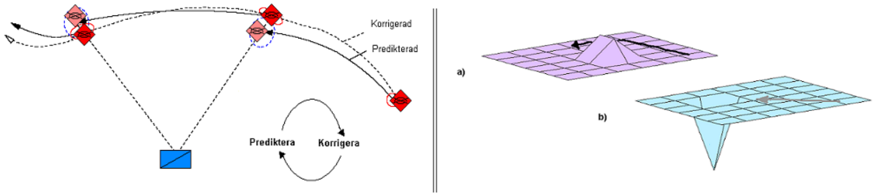

Fig. 8. To the right the principle of Kalman-filter and to the left the dynamic model, the terrain (a) and the main heading (b).

Neural Networks

Neural networks, here the artificial ones (compared to the biological ones), works by learning and the knowledge is then stored in the synapses. The principle of neural networks (NN) is described in Fig. 9 (left), above the synapses with weights and the neuron that sums up the incoming signals and below a neural network, very simple, with input and output. More theory on neural networks can be found in Thomas (2003). Using neural networks for prediction is quite common, like in the economics. Following is an idea how neural networks could be used for prediction in this case, based on an article by Hill et al. (2002). The basic idea is to use a sector divided into smaller sectors, that search the terrain data and gives the sector pieces different probabilities, where the coming direction is given by the sector piece with the highest probability (Fig. 9, right). This probability based on the terrain could be enhanced by the main heading (Fig. 9, right (2)). Looking closer to the process described in Fig. 9 (right), number (1) is the old observations of a vehicle, the historical data, that are used to find out the main heading (2). A short prediction can be made based on resent observation of the vehicle (3), speed and direction. The following steps (4) and (5) is using the sector to find the path with highest probability.

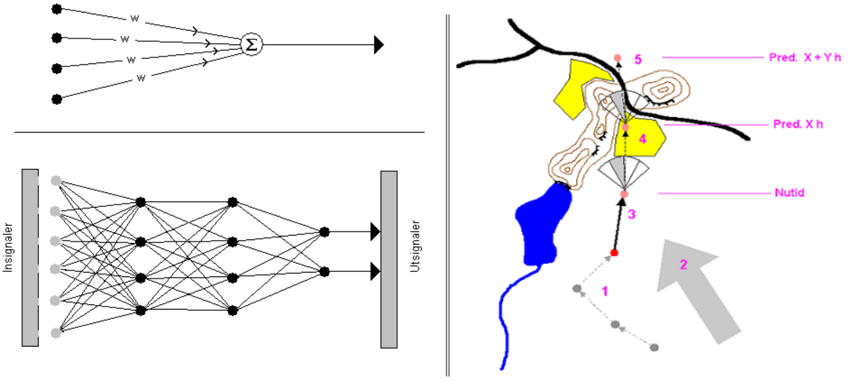

Fig. 9. To the left the principle of neural network and to the right an idea of how neural network could be used for prediction in this case.

3.5 Uncertainty, an issue for the commander

In the end it is very important that the basic sources used for the prediction is of high quality. At least the uncertainty should be known and described, so that the uncertainty of the final prediction can be presented in a proper way for the commander. The commander can then use this when making a decision. Improvement of quality of the data can always be done in every step of the OODA-loop and it should absolutely not be ignored.

More research is certainly needed to make the prediction process work and to get the wanted result. Especially the methods and algorithms for prediction need more research to find the best method. Also the basic data used need improvement, the errors needs to be minimized. Last, what needs to be remembered is that this is only a first draft for a working system for prediction, and thereby it's not based on any existing one.

4 Development of visualization for the situation picture

This part of the paper is based on Master's Thesis by Salonen (2005) and uses the results from the previous chapters.

4.1 The problem given and the objectives

The goal of this study was to develop visualization of the situation picture so that all essential things are shown in the maps clearly and reliably to a decision-maker. The main task of this study was to define new map types for the situation picture application and suggest clear and informative presentation of the maps. The visualization of the situation picture supports the data and the information process to the knowledge and the vision.

4.2 Materials and methods

The maps in the situation picture application can be divided into topographic and thematic maps. Topographic maps are basically maps in scales 1:50 000 and smaller and they are used as background maps. The topographic maps used at the moment in situation picture are the regular printed maps. They are not suitable for the screen and do not fit with the colours of the standardized colours of military symbology. Thematic maps visualize the results of terrain analyses like cross country analysis, visibility and accessibility. Some of them are ready calculated map layers with predefined map design but the majority of them are computed on-line and no visual designs exist for them.

Also the visualization of the quality of both observations and analyses were among the given tasks and for that not many examples exist even in the literature. Uncertainty to be visualized was the thematic quality of observations (correct classification) and uncertainty of visibility buffer (area around the boundary of the visibility polygon). Visualization of the temporal quality of the observations was also to be solved; there was a need to discriminate observations in history, at present and in the future (predicted).

In order to produce improved visualizations new maps were designed and implemented by the ArcGIS software. A user test was organized in order to be sure about the usability of the designed maps (Salonen, 2005).

4.3 Results: The maps for the situation picture application

The own troops, enemy troops and tactical plans have been presented in the situation picture maps according to the standard Mil-STD2525B (2004). These tactical symbols have presented bright colours, which cannot be easily distinguished from the colourful topographic background map is used. The main design task of this work was the colour design task. The other map design problem was the generalization of the background map. This problem was solved with Ravegeo – application, which enables to use a vector map in various scales, like in this case NLS Topographic Database, Figure 10.

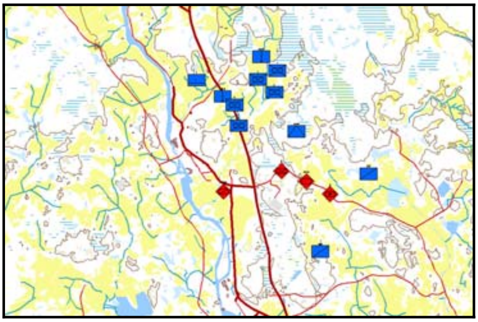

Fig. 10. Generalized vector map (by RaveGeo application) in the situations background.

The evaluations of maps and usability tests are an essential part of a map design process in order to achieve visually appropriate presentation of the map. The usability test of the situation picture maps confirmed the meaning of colours in the background maps. The situation comes out more clearly if the colours of the background map are changed more light-coloured (less saturation). The most recommended alternative of the background map was the vector map, which is flexibly to edit and update. Thereby the vector maps could consider better the requirements of the users.

4.4 The user interface of the situation picture application

The user interface of the situation picture application enables a user to look at the situation in several map views and also to study the statistics and the tables at the same time. In the map views the background map of the situation can be not only a terrain map, but also a thematic map. The thematic maps can be either a result of spatial analysis (like a viewshed) or a raster layer (like a cross-country mobility). The other thematic maps are the accessibility and route map or the density map.

4.5 Representation of the predictions, temporal quality

Based on the previous chapters are known that the situation picture is formed of the observations (Seppänen, 2005) and the predictions (Janlöv, 2005). The collected situation information can be presented as a so-called "history, present and prediction"

–map that presents movements of the troops by changed tactical sings. This map is a one stopped moment of the situation. In this map the history data was presented by the transparent tactical symbol and the prediction data by the clarity edge of the tactical symbol, Figure 11.

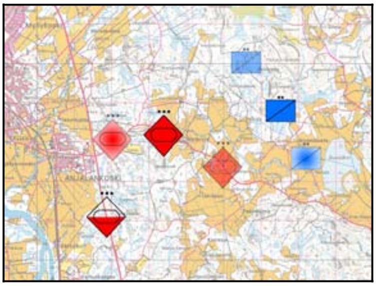

Fig. 11. The movements of the troops by the changed tactical sings. This map also includes the one tactical symbol (filled only half way) that presents an uncertain observation.

4.6 Representation of the uncertainty, spatial and thematic quality

One visualization task was to develop methods for visualizing the uncertainty of the maps. In the situation picture application it is crucial for the commander to recognize the information that is more reliable than the other. The uncertainty of the observation was represented with changed tactical sing. The uncertain observation has the own symbol in the situation map, which is the tactical symbol filled only a half way, Figure 11.

The boundary line of the viewshed is not usually exact, unless the visibility stops to the buildings. The uncertainty of the viewshed boundary line can be presented with the wider, light grey fuzzy line. The black, thin line represented the precisely known boundary line of the viewshed.

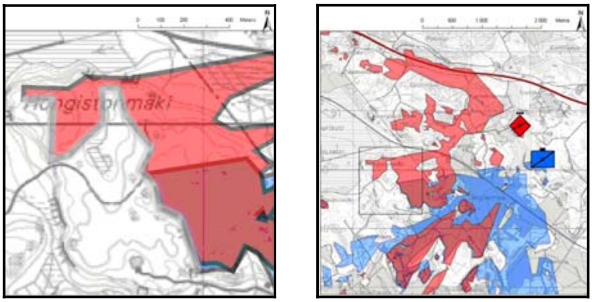

Fig.12.: Uncertainty of the viewshed boundary line can be presented with the wider, light grey fuzzy line.

5 Conclusions and further research

In this project the goal was to show the possibilities of the use of GI and analyses as well as visualization in the military situation picture application. The task was to find the suitable and available analysis functions among the ready made routines of the given platform and also test the suitability of them.

Some of the algorithms, like accessibility, were found to be too slow and inefficient for the required fast computation. Those problems can be solved by decreasing the resolution of the source data and also by using customized functions that apply more advanced algorithms. Another problem is the algorithms for visibility analysis because the required source data is not always available. Visibility needs updated information about vegetation and also utilizes information about the climate and light conditions. This kind of source data is not available.

One of the most interesting problems to be solved in this research will be the algorithm for the prediction of the enemy movement. Our proposal until this is to use Kalman-filter based algorithm.

In the visualization there is still work to be done with the entire user interface and some details like the "fuzzy" boundary on uncertain area of visibility.

These problems will be tackled during this year when we develop the prototype of situation picture application. The prototype will be implemented by using the new ArcEngine –component library of ESRI. A more basic research oriented topic has also risen from this work: the information management and presentation for the commander as an entire process utilizing even more advanced GIS –technology like spatial data mining and multivariate visualization.

References

ArcGIS (2004). ArcGIS 9.0 Help, manual. [Electronic]. ESRI.

ArcGIS (2002). ArcGIS 8.3 Help, manual. [Electronic]. ESRI.

Hill, R. W. (2002). *Anticipating where to look: predicting the movements of mobile agents in complex terrain*. [Electronic]. PDF-format. Presented at First International Joint Conference on Autonomous Agents and Multiagents Systems, Bologna, Italy. Available: <http://www.ict.usc.edu/publications/aamas548.pdf>.

Hyytiäinen, M. (2003). *Geographic information superiority in the digital battlefield.* Sotilaallisten maastoanalyysien metamalli. Julkaisusarja 1, N:o 1/2003. Taktiikan laitos. Maanpuolustuskorkeakoulu. Doctor's thesis. Helsinki: Edita Prima Oy. (in Finnish)

Janlöv, M. (2005). *Predicting the movement of an object in the situation picture of the army using topographic data – factors, methods and uncertainty*. Master's thesis. Helsinki University of Technology. Department of Surveying. Espoo. (in Swedish)

Mil-STD2525B. DISA (Defense Information Systems Agency). <http://symbology.disa.mil/symbol/mil-std.html> (Read 9.12.2004)

Nenonen, J. (2003). Creation of situation picture of mechanical troops at 2010. Publication series 1, N:o 15, Institute of technology, National Defence Academy. Helsinki: (in Finnish)

O'Sullivan, D., Unwin, D. J. (2003). *Geographic Information analysis*. New Jersey. John Wiley & Sons Inc. 436 s. ISBN 0-471-21176-1.

Piiroinen, P. (2003). *The meaning of information in the defence of Finland.* Verkkotaistelu 2020, 2/2003. Maanpuolustuskorkeakoulu. Helsinki. EditaPrima Oy. 111s. ISBN 951-25-1423-0. (in Finnish)

Salonen, T. (2005). *Developing the visualisation of GI for military applications*. Master's thesis. Helsinki University of Technology. Department of Surveying. Espoo. (in Finnish)

Seppänen, H. (2005). *The automatization of the creation of situation picture by using GI and GI –analyses.* Master's thesis. Helsinki University of Technology. Department of Surveying. Espoo. (in Finnish)

STAE (2004). *Development of defence systems.* Evaluation and prediction. 2020, STAE 2020, osa 2. Helsinki. Edita Prima Oy. 418s. ISBN 951-25-1533-4.(in Finnish)

Strang, G. & Borre, K. (1997). *Linear Algebra, Geodesy, and GPS.* Wellesey-Cambridge Press. USA.

Thomas, B. (2003). Framtidens intelligens: En bok om AI, återkoppling och neutrala nätverk. Lund: Studentlitteratur. (in Swedish)