Using the impact matrix for predictive situational awareness

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Abstract –

In order to manage situations efficiently, commanders need to be aware of possible future events that might occur. They also need to be aware of the relative probabilities of different events, so that they know which events to take into account when making plans of their own. In this paper, we describe a concept prototype that was developed at FOI during 2006 that helps commanders do these tasks.

The impact matrix is a tool that has been used in business for risk handling. We describe the impact matrix and how it can be adapted for military use. To connect observations from soldiers and sensors to events, indicators are used as tags. Belief networks are used to connect indicators to events. Results from a preliminary experiment using a scenario based on an asymmetric conflict where a Swedish battle group is tasked with preserving peace are presented.

Keywords: Impact assessment, threat assessment, belief networks

1 Introduction

Information fusion deals with the task of filtering, sorting, analyzing and fusing information in order to help decision makers achieve situational awareness. The data and information which is processed comes from a wide variety of sources, ranging from sensors (radars, IR-cameras ,…) to natural language reports from reconnaissance soldiers or intelligence analysts. Traditionally, military information fusion dealt with scenarios that involved a high-technological adversary that waged war against us. The opponent was assumed to be similar to us in organization and goals, and hence this type of war is sometimes referred to as symmetrical warfare. In such scenarios, most of the information that comes from sensors and humans is highly structured, which facilitates the analysis and fusion of them. One example of this is the so-called "7S"-format[1] for reports traditionally used by the Swedish armed forces. Signal processing can in this kind of scenarios be used to automatically classify vehicles that are passing, and the information about the position and type of vehicle can be used to aggregate the sensor reports into clusters that correspond to platoons and companies of enemy vehicle. For an example of what is possible to achieve in such traditional warfare scenarios, see [1] and [2]. Most of the methods used for traditional information fusion rely heavily both on the structured content of the input data and on the presence of reliable templates and doctrines for how the adversary behaves.

Such methods can however not be used when faced with the kind of opponents that the Swedish armed forces meets today in. In UN missions toaday and in the operations of the future European Battle Groups, we face situations that are completely different from those used in the old scenarios.

In today's international peace-keeping and peace-enforcing missions, the "adversary" is normally a multi-faceted loosely-coupled combination of well-armed soldiers, irregular forces, criminals, civilian groups and other entities, using various types of vehicles and low or high-level technical equipment. These actors interact with sometimes hidden and non-correlated agendas, and collaborate if they judge it to be supporting their specific goals. In order to support the mission goals, our troops sometimes have to counter-act their objectives; this will make them regard us as an enemy. They try to find our weaknesses in unconventional ways, and often use technically primitive weapons. Due to their loose organization, they are very difficult to regard as a physically well-defined adversary. All of this, taken together, forms what has come to be known as an asymmetric threat. The asymmetry comes from the fact

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[1] "7S=Stund, ställe, styrka, slag, sysselsättning, symbol, sagesman", Swedish for "time, location, strength/ number, type, activity, symbol, source".

that the opponent is much less organized than we are, have different types of equipment, and have goals that we might not know. Note that it is not necessary that the opponent lacks access to high-technology weapons and material: but if they have it, it will be COTS products, not originally designed for war. The opponent is also asymmetrical in the sense that they are not bound by the same rules of engagement as we are. Terrorists, for example, do not follow the Geneva convention and other laws of war.

Even if we still have to be ready for facing a "classical" military adversary with its arms, vehicles, sensors etc, the "normal picture" in international missions is often dominated by such asymmetric threats. Intelligence information gathered during a mission under such threats can often be disparate and difficult to use for understanding what could be going on. Some pieces of information can be more usable than others when trying to figure out what possible goals the enemies have. Some other pieces of information tend to indicate that some type of event could be going on, and sometimes the combination of several obtained pieces of information makes some specific course of action much more plausible. Efficient tools that make it easier to reason about possible future events can give us time to counteract undesired events. Such tools will help us achieve situational awareness, which can be defined as knowing what the opponent is doing and why they are doing it [3].

In this paper, we describe a tool that aims at helping decision-makers and intelligence analysts to sort and filter the reports that they receive about an area of operations. The tools is based on the concept of an impact matrix, which has been used in business for risk analysis for some time. The impact matrix is originally just a static picture that acts as a reminder to the decision-maker: it simply lists a number of possible future events that might impact the decision-maker. Here, we add a dynamic component to the tool. By connecting incoming reports from sensors and human observers to the events that they might influence, we dynamically re-calculate the probabilities of the events and display this information to the user. In the current implementation we use Bayesian belief networks to calculate the probabilities. The impact matrix can be seen as one way of sorting the incoming reports and allowing the user to select different views where only those reports that are connected to the event that the user is considering are shown. Reports can in this case be connected to several different events.

This paper is outlined as follows. First, we briefly describe the static impact matrix as used in previous applications. We then describe how we connect the reports to the events by the use of so-called indicators, which can be thought of as tags that are attached to the reports. The

scenario used and the user-interface of the software is described next, and we conclude with future work.

2   Impact Matrix

The Impact matrix (IM) is a tool that help users remember the probabilities and impacts of various events that might occur in the future and which will have an impact on the user. It was used in the "Demo 06 Vår" demonstrations at FM Ledsyst UtvC in Enköping and is briefly described in [4].
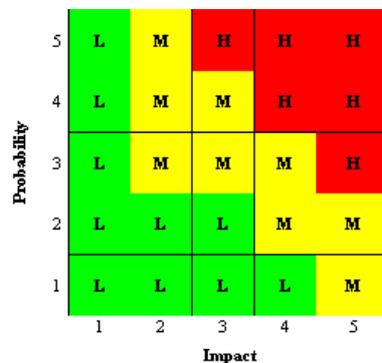
The IM has been used for many years in the private and public as a tool for environmental scanning and risk assessment. The IM can be used for many different applications, including

- Risk analysis
- SWOT analysis (strength-weaknesses-opportunities-threats analysis)
- Pattern recognition

H= High

M=Medium

L=Low

Figure 1. Example of an impact matrix. This is simply a visualization of a number of events that are of interest, sorted according to a priori probability and impact.

Figure 1 shows an example of a static impact matrix. This figure shows how different possible future events that the user is interested in could be sorted according to the estimated a priori probability with which it will occur and the estimated impact the event would have on the user if it happened. Events that are both likely to occur and that will influence the user greatly are placed on the top right quadrant, while low-impact events that we do not think will happen are placed in the lower left quadrant. The goal of the impact matrix in this form is to help the user remember those events that they have previously determined to be important to them. It is simply a sorted list.

A static impact matrix such as this is assumed to be output by the planning compartment of the field headquarters of a battle group.

In the concept demonstrator presented here, we take the impact matrix one step further by including a semi-automatic coupling to real world events that change the probability that an event is occurring or will occur in the near future. This is done by coupling incoming HUMINT reports to indicators [5, 6], that give a high-level description of what they are about. Indicators, as used in this prototype, could be compared to tags as used in a wiki or collaborative database to mark things. The indicators are assumed to be attached to the reports either automatically or (most likely) by human operators that monitor sensors and incoming reports. It is worth pointing out here that the concept of indicators as used by us here is very similar to the way that information gathering is today handled by the Swedish special forces: the reconnaissance soldiers provide similar tags in their reports.

Indicators are via a so-called Bayesian network linked to hypotheses about the realization of events; that is, the indicators put together give different probabilities that a certain event will happen. When the probability of an event changes, it is indicated in the matrix by changing the colour of the event. Thus, by looking at the matrix, it is possible for the user to immediately spot events that are happening right now, leading to increased situational awareness.

We deliberately chose not to move around the events in the matrix in order to show the changing probability. Instead, the visualization provides information both about the currently estimated probability (the colour of the event) and about the a priori probability that was estimated during planning (the vertical placement of the event). This makes it possible to quickly find both events that have high current probability and those which have a low current probability but had a high a priori probability. The latter kind of events are also important for the decision-maker to be aware of: they can be an indication that the planning process must be modified, or it might be the case

the event is taking place, but we do not have information gathering resources that can find the relevant indicators.

We envision the tool mainly to be used in the JOC[2] to keep track of what the different pieces of situational information received so far reasonably could say about the future. Thus it is, in short, a tool to help the JOC staff to manage events and indicators. The main idea is to speed up the process of transforming incoming intelligence to an as good as possible situational awareness. The program helps the analyst to keep track of the relations between indicators and events and to model the relations in detail using, in the current version of the program, belief networks.

A current limitation in our tool is that it does not handle conditional probabilities, i.e. if an event A happens, how will that influence the probability that some other events will happen. Also, it will not flag that events can be mutually exclusive or conflicting.

3   Scenario

To test our developed softwares, we needed a scenario of peace-keeping or peace-enforcing character. The so-called "Bogaland" scenario was developed by the Swedish Armed Forces to be used at the "Demo 05 Höst" and "Demo 06 Vår" demonstrations at FM Ledsyst UtvC in Enköping, as well as during the "Viking 05" exercise. We studied this scenario, but it was not followed by us in detail, rather the scenario was used as an inspiration. The scenario contained too few detailed intelligence reports on what could reasonably have been observed in such a mission. Therefore, with this scenario in mind, we invented reports that could typically be generated from observations, and received from other channels such as news or allied troops.

We focused on the "South-Mida" part of Bogaland, and Norrköping as the main town in the imagined Swedish (or future NBG[3]) AOR[4]. A set of 64 reports constituting "typical" observations in such a scenario was generated. The reports had various depth in detail and tactical "level" ranging from pure observations such at "X and Y was seen having a meeting at corner Z to general news such as "The Bogaland legal government in Stockholm has decided to…". For the demonstration, a subset of these reports was used. We also generated a list of events that could happen and the indicators that are associated with them, as well as the Bayesian networks needed to link the indicators to the events. The connection between observations and

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[2]   Joint Operations Centre
[3]   Nordic Battle Group
[4]   Area Of Responsibility

indicators was done manually, using a separate program. In the future, it would be interesting to investigate how this could be done semi-automatically.

We did not aim at complete realism in the reports or the networks that link indicators to event. Instead, we tried to make them realistic enough that the concept that we are trying to demonstrate is made clear.

4   Implementation

As described in the introduction, the Impact matrix is used for structuring possible future events based on how likely they are to occur and what the impact will be if they do occur. In its simplest form, the matrix consists of four fields corresponding to {low probability, low impact}, {low probability, high impact}, {high probability, low impact} and {high probability, high impact}. For each event in the matrix, a number of *indicators* are listed. The indicators are examples of observations that can be made which indicate that a particular event is about to or already has occurred. Intelligence received during the execution of a plan is manually mapped to events either directly or by comparing them to the lists of indicators.

We have developed a computer program to facilitate the management of events and indicators. The main idea is to speed up the process of transforming incoming intelligence to an as good as possible situational awareness. The program helps the analyst to keep track of the relations between indicators and events and to model the relations in detail using, in the current version of the program, noisy-and-or belief networks [7].

4.1   User Interface

The central view of the program interface is the Impact matrix itself with its four fields with different values for event impact and likelihood. The interface, as shown in figure 2 below, also displays a list of reports that belong to the currently selected event, a description of the event and its indicator, a map where the locations (if there are any) of the reports are shown, and a panel where more information about either an indicator or a report can be shown. The colour of an event indicates the observed probability of it happening; i.e., it increases when more indicators for that event have been observed. The information given is also, when relevant, linked to more information in the MilWiki [8].
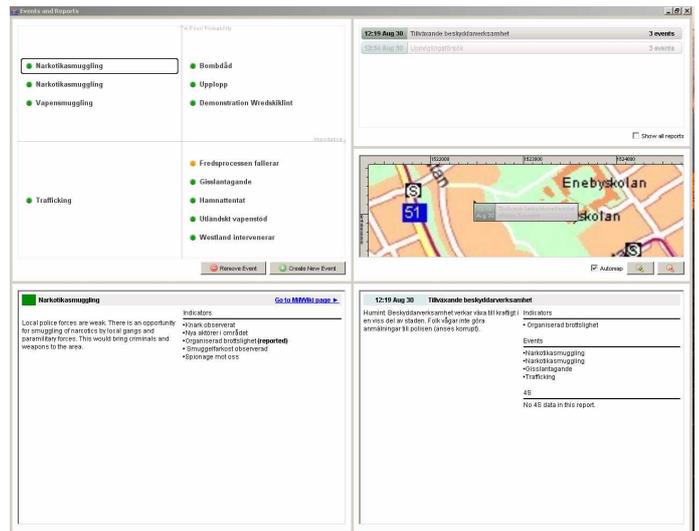

Figure 2. **An overview of the user interface of the impact matrix program.**

4.2   Modeling events with belief networks

Belief networks are used to model (causal) relationships between events. By specifying which event depends on which, the number of parameters to consider when determining the probabilities of a specific events to occur can be reduced. An event can be described as a combination of a *variable* and its *value*. The event "the weather is sunny" is composed by the variable "weather", which can take numerous different values, in this case "sunny".

In our program, we model indicators and events as nodes and use noisy-or and noisy-and calculations to connect them. The editing facility of our program allows the user to construct the belief network and also to choose if an event should rely on the OR-principle or the AND-principle (known as the Noisy-Or and Noisy-And models). It is also possible to set the strength of each indicator's influence on the event. Figure 3 shows an example parameter setting. By sliding the rulers corresponding to parent-nodes to the selected event, the conditional probability table for the node is changed.
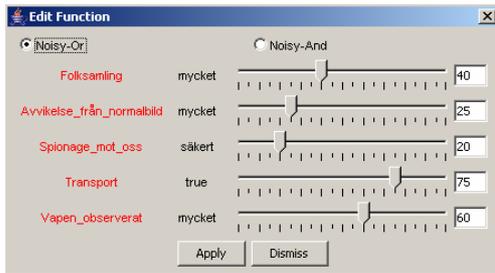
Figure 3. **Example parameters for an event which is influenced by several different indicators and hidden nodes.**

Our program allows the user to directly edit the network that connects the indicators to an event, as shown in figure 4. We have used the JavaBayes toolkit to get the belief network functionalities needed for our prototype.
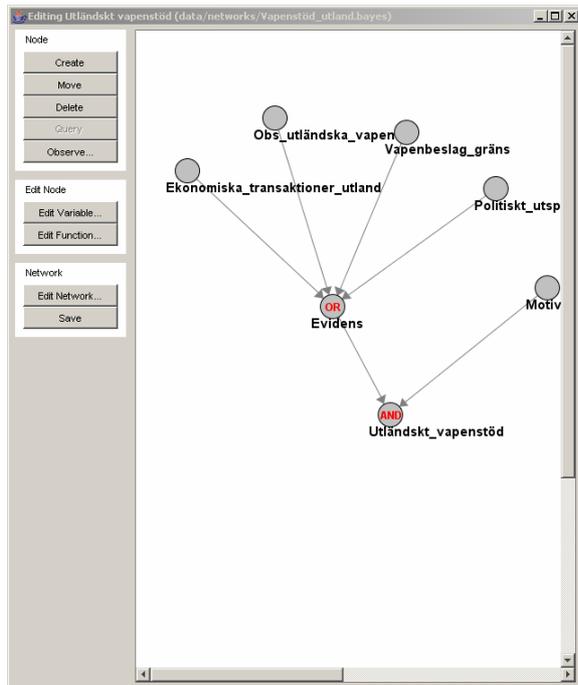

Figure 4. **This figure shows how it is possible to edit the network that connects the indicators to the event. Note the use of several layers in the network (the or-node "Evidens" is introduced as a help for the user that is modeling the event).**

This would most likely occur in the planning or intelligence sections of the FHQ.

The user interface is shown again in figure 5 below. The impact matrix is shown at the top left of the interface. To the right of this there is a display panel that shows reports belonging to the selected events. There is also a map area and a section where more detailed information about a report can be shown. Below the impact matrix, it is possible to view more detailed information about selected events.

4.3   Evaluation

Evaluation of a concept prototype such as this has to be done on at least two levels. First, the algorithm used to calculate the probabilities displayed in the impact matrix have to be compared to other approaches and the best one chosen. Second, it is necessary to perform user experiments to determine if the tool actually leads to increased situational awareness.

We are currently looking in to several possible enhancements to the algorithm used in the prototype described here. Among other things, we would like it to be possible to set an expiration time on indicators, and also to have more advanced handling of uncertainties in the input data.

In the fall of 2007, we will conduct user experiments on this tool. Initial results from small-scale experiments and interviews performed during the first half of 2007 indicate that the impact matrix tool is useful and helps the decision-makers achieve better situational awareness. When showing the prototype to users who have been in service in Kosovo and other places, we have received several interesting suggestions for other uses of the tool. The impact matrix could be used to display information about what NGO's and other civilian actors in the area are doing. It could also be useful for training and for debriefing, where it would be useful to replay the events that have taken place and see what other actions could have been taken. Interestingly, a company commander also suggested that he would have liked to have had access while in the field to an annotated picture of the impact matrix display, where analysts at the FHQ had added extra information.
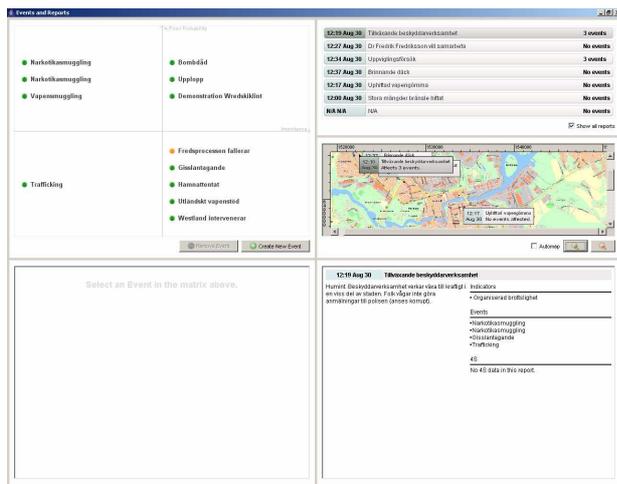
Figure 5. **The user interface of the "impactorium" program, shown for a situation where a number of indicators have been observed. Note that the calculated probability that "fredsprocessen fallerar" ("the peace process will fail") is rather high.**

5 Future work and summary

The described program is an example of how information could be handled in order to assess the possible intents of the adversary, as well as from available information try to hypothesize about future events on an operational level. At the demonstration for the Swedish Armed Forces that took place in 2006, we also showed a prototype that implemented a version of capabilities-based aggregation [9, 10]. This program allows commanders to see what own objects or objects that we are tasked with protecting that are in danger because the opponent might have the capability to harm it. An interesting possible future work is to connect these two tools. This would give us a link between two different kinds of situational pictures, one which relies heavily on using a map to display information and one which does not.

The Impact Matrix tool does not try to be very "smart". It has been designed to be a help in keeping track of which available information could be linked to potential future events. There has to be a well skilled person that can identify what indicator(s) a received piece of information or intelligence actually contain. Furthermore, the design of the belief network, and the estimation of the weights in the network is another manual process. The knowledge of an expert should ideally be implemented as the structure and weights in the network. It is vital that the person that is the knowledge source has a good knowledge of what indicators are typically more or less important precursors for a specific event to happen. The network should be enough developed before the mission starts by implementing "common sense" in it, as well as knowledge that is normally valid for most types of missions. But few

knowledge bases are perfect or complete. During the ongoing mission, the structure and weights of the network could be changed in order to correct form new knowledge collected. That is; if unknown relations between indicators and events emerges [5, 6], this should be reflected in an updated network. A tool that helps the expert in updating the network with new knowledge should be a natural extra component to our example tool, but has not yet been designed.

We see several possibilities for future work on the concept described in this paper. This year, we are undertaking a set of user experiments with the impact matrix to determine how it could be used and what roles should have access to it. These experiments will seek to determine if the tool aids commanders in achieving situational awareness by comparing its use to more traditional ways of handling information. Preliminary experiments indicate that the tool is helpful, but that the commanders want to be able to understand how the computer has reasoned in order to compute the probabilities. This is an argument both for keeping the belief network models as simple as possible and for teaching future officers more about belief networks.

We are also looking into how it could be combined with observations about own movements and status to help commanders estimate if the actions they have ordered lead to the desired effects or not. In collaboration with Singapore, we are looking into how to use web mining tools and semi-automatic classification of retrieved information as input data for the impact matrix. We are also investigating how to make it easier for soldiers or analysts to tag observation reports with indicators using taxonomies and natural language processing techniques to suggest the most probable indicators to the operator. Other possibilities for future work include building tools that make it easier to build the belief networks needed in the tool and trying to connect the impact matrix to the capabilities-based aggregation [9,10] and plan recognition [11] work done previously.

More details about this ongoing work as well as about other information fusion research at FOI will be presented in a follow-up paper [12].

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