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The Management of Geographic Information Flows in Crisis Situations

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ABSTRACT
This paper studies the management of geographic information and knowledge flows for decision support in crisis situations. The authors compare and contrast a number of concepts that have been forwarded by academics as possible methodologies for the study of this area. The authors believe that they may have found an answer using system models combined with decision-making, information management and geographic information management models. Especially, the authors apply a system model about situation awareness. This model reflects to a state where a comprehensive mutual understanding and sharing of ideas between the decision-makers are provided. It supports the categorizing of geographic information and knowledge according to the user specific value and updating frequency. Currently a prototype of a decision support system based on the model is under development.

Keywords
Geographic knowledge management models, decision support, complex systems

INTRODUCTION
The introduction of global networks and structural changes in societies have created new types of potential and realized threats to the societies and to the citizens. These new types of threats have been an object of study since the end of the cold war. They extend the need for managing geographic information flows for decision support beyond the traditional scope of military affairs. The Finnish Government (2003) published a government resolution and strategy for securing the functions vital to society in 2003. This strategy says that the currently identified threats in Finland include threats to information systems, illegal entry and population movements jeopardizing security, threats to the nutrition and health of the population, environmental threats, economic threats, organized crime and terrorism, disaster situation, international tension, serious violation of territorial integrity and threat of war and armed attack and war (The Finnish Government 2003). These threats are typical threats to a modern society. The wide scope of the threats and the structural changes in societies has made the group of organizations that are needed when implementing the protective activities against the threats quite large. Typically, the protective activities are performed in the networks of state authorities, private companies and interest groups. The cooperation between all these organizations and their decision-making bodies is challenging. Quite often the decision-making bodies have not yet even agreed about the meanings of all the basic concepts of crisis situations. This includes the concepts related to the management of geographic information flows in crisis situations. So, there is a need to clarify these concepts to improve the shared understanding among the authorities.

The activities to protect the society from the threats are typically performed under the title of national security. The management of information flows is in a key position when developing the national security. Malone (2003) argues that the national security is protected with the information component of the national power by implementing the following tasks: intelligence, counter-intelligence, national information infrastructure protection, perception management and information operations. These tasks include the management of information and knowledge flows to create situational awareness about the current and future threats and crisis situations. In Finland the need to develop enhanced situational awareness by collecting, analyzing and editing information under the Prime Minister’s office has been recognized (The Finnish Government 2003). However, the contents of situational awareness concerning threats and crisis situations have been defined only at a rough level.

Information and knowledge flows in crisis situations contain geographic information and knowledge that has a spatial component. Approaches to the management and analysis of spatial information for decision support have been studied in the field of spatial decision support systems (SDSS). A SDSS is a special type of decision support system (DSS). A DDS provides a set of tools in a computer-based environment for collecting, storing, exchanging and analyzing information (Marakas 2003). Since the mid-1990s DSS and GIS have been related to Internet technologies and online applications (Rinner 2003) and used for group-decision-making (Armstrong & Densham 1995). The spatial aspect to a DSS contributes to
the development towards such architecture. Multilateral Interoperability Programme (MIP 2004) and its C2 information exchange data model (C2IEDM) are examples of information architecture describing the geographic information and knowledge categories that will be shared is defined. The geographic information architecture. So, the implementation of the national security DSS requires that a geographic organization. The shared use of geographic information in crisis situation requires that the decision-making authorities share information content restricted piece of information that has a wide effect. Both aggregation and non-linearity are widely aggregated information is non-linear: even the highest level authority need to focus on spatially or by information. Typically, the more high level authorities need the more detailed information. However, it shall be noticed that the aggregation of information is often non-linear: even the highest level authority need to focus on spatially or by information content restricted piece of information that has a wide effect. Both aggregation and non-linearity are widely known characteristics of dynamic systems, e.g., (Holland 1995). Traditional approaches to top-down or bottom-up aggregation include generalization of geographic data for map production. Observed data are categorized to higher level object classes during the generalization work. The object classes are included in the information architecture of an organization. The shared use of geographic information in crisis situation requires that the decision-making authorities share the geographic information architecture. So, the implementation of the national security DSS requires that a geographic information architecture describing the geographic information and knowledge categories that will be shared is defined. The Multilateral Interoperability Programme (MIP 2004) and its C2 information exchange data model (C2IEDM) are examples of the development towards such architecture.

In this paper, the authors compare and contrast a number of concepts that have been forwarded by academics as possible methodologies for the study of the area of the management of geographic information flows for decision support. First, the authors analyze concepts related to information, geographic information and time to outline the basis of the study. Secondly, the authors combine decision-making, information management and geographic information management models to create a model about the phases of national security decision making. Then the authors refer to a system model about joint situation awareness to understand the basis of information and knowledge categorizing for decision support. The authors apply the model to the management of geographic information and knowledge flows in crisis situations to support the development of a national security DSS. The national security DSS is a web-based application that contains spatial technology. It assists the state authorities in crisis situations.

INFORMATION, GEOGRAPHIC INFORMATION AND TIME

Geographic Information Classes

In the crisis situations the decision-makers need a relevant set of futures oriented geographic information and knowledge in a form that suits their competence and technical requirements. The analysis of the basic concepts related to information, geographic information and time supports the identification of the types of information that the decision-makers need. Definitions and classifications of the concept of information are numerous and have varying roots and backgrounds in several scientific disciplines. One of the most common approaches to classify information is to form three information level classes: data, information and knowledge (Maier 2001). In ICT-literature data are typically defined as known facts that can be recorded (Elmasri & Navathe 2000). Data are suitable for communication, interpretation, or processing by humans or artificial entities. Information is usually defined as structured data useful for analysis (Thierauf 2001). Information has a meaning, purpose and relevance (Awad & Ghaziri 2003). Knowledge is often defined as ‘the ability to turn information and data into effective action’ (Applehans et al. 1999). Maier (2001) gives a broad definition of knowledge stating that ‘Knowledge comprises all cognitive expectancies that an individual or organizational actor uses to interpret situations and to generate activities, behavior and solutions no matter whether these expectancies are rational or used intentionally’. This definition emphasises the creation and dynamics of knowledge. Geographic information concerns objects or phenomena that are directly or indirectly associated with a location relative to Earth (ISO/TC 211). When the classification of information into data, information and knowledge is applied to geographic information, three classes of geographic information are formed: geographic data, geographic information and geographic knowledge (Peuquet 2002). Geographic data, information and knowledge consist of spatial and attribute data, information and knowledge. It can be assumed that the national security DSS shall contain information of all these six types. The DSS shall provide geographic data and information in such a form that the decision-makers are able to turn the provided data and information into effective action.

In addition to the hierarchical levels, information can be classified based on its quality and accuracy. Usually, state level authorities need a rough level picture of the current situation while regional and local authorities need more detailed information. Typically, the more high level authorities need the more aggregated information. However, it shall be noticed that the aggregation of information is often non-linear: even the highest level authority need to focus on spatially or by information content restricted piece of information that has a wide effect. Both aggregation and non-linearity are widely known characteristics of dynamic systems, e.g., (Holland 1995). Traditional approaches to top-down or bottom-up aggregation include generalization of geographic data for map production. Observed data are categorized to higher level object classes during the generalization work. The object classes are included in the information architecture of an organization. The shared use of geographic information in crisis situation requires that the decision-making authorities share the geographic information architecture. So, the implementation of the national security DSS requires that a geographic information architecture describing the geographic information and knowledge categories that will be shared is defined. The Multilateral Interoperability Programme (MIP 2004) and its C2 information exchange data model (C2IEDM) are examples of the development towards such architecture.
Geographic Information and Time

Time provides another perspective to classify information. McTaggart (1908) states that time can be studied by two time-series, A and B. Series A divides the temporal word to the past and to the future, which are separated by subjective, ever-changing experience of “now”, and describes the world as a sliding duration, which is tied to the reality with subjective experience of the present moment. Series B divides this world into separate measurable moments, which have taken place either before the measured moment of “now” or will happen after it, while filling the world with temporally noticeable events, which have starting and ending moments that are measurable. (McTaggart 1908) Both series provide a theoretical model to classify information based on its temporal nature. When time series A and B are used for studying the temporality of information, three classes of information are identified: memories as information about the past, perceptions as information about the current moment and assumptions about the futures as information about the futures (Bergson 1911; Damasio 1999). The aim of the national security DSS is to support the preventing of the threats to the society. This requires that the DSS provides the decision-makers with functionality and information to anticipate the evolvement of potential crisis taking place in futures. Anticipation uses information about the past, information about the current moment and information about the futures as source information and it produces information about the futures. So, the DSS shall be able to manage information of all the temporality types. In addition, it shall emphasize the management of geographic information flows about the futures.

Mennis et al. (2000) offer a pyramid data model as an approach to combine geographic information and time. The model consists of three data components that are location, time and theme and a knowledge component (Mennis et al. 2000). Location is part of the spatial data of the previously presented definition of geographic data. Time and theme cover all the other aspects of geographic data. Mennis et al. (2000) write that knowledge component represents derived knowledge interpreted from the observational data. The model moves directly from geographic data to geographic knowledge without the intermediate geographic information step in the knowledge development process and representational structure. The model contains interesting features from the national security DSS point of view. Especially, it presents a structure about attribute, location and time data and geographic knowledge. The model considers time to correspond to the when perspective of cognition and regards it as a duration between separate measurable moments (Mennis et al. 2000). So, it describes the temporality of data by using the concept of an event. An event starts on a measurable moment and ends on a measurable moment. This modeling suits well the requirements of the national security DSS. In the DSS, the implementation of the concept of an event can be used for managing the temporality of information concerning the threats. A threat is modelled to consist of one or several short-term and long-term events. Events have already happened, they are happening now or they will happen in the futures. It is the role of the decision-maker to anticipate the starting and ending moments of the events that will have an effect in the futures or that are effecting now.

Deriving of knowledge from information and data is a bi-directional cycle (Maier 2001). Mennis et al. (2000) argues that the pyramid model contain the knowledge development process. However, the cyclic nature of the knowledge development process is not clearly present in the pyramid model. The national security DSS needs to be based on a cyclic view to the knowledge development process. For example, the DSS shall support the decision-makers in anticipating the potential usage of resources in crisis. The plans of resource usage are based on data about available resources and knowledge about the resource needs in the threat situations. That knowledge need to be turned into information and data when forming the resource usage figures of the plans.
In the national security DSS geographic information has to be acquired, created and analysed for decision-making and disseminated for an action. The pyramid model does not describe this cycle of the management of geographic information flows. In addition, the management of geographic information flows takes place in several hierarchical levels such as the state level, regional level and local level. All of these levels have a level specific duration to implement the information flowing cycle. The pyramid model does not directly support the modelling of the hierarchy of available durations. If a decision-making unit needs longer duration to implement the information flowing cycle than what is available the unit is in chaos. This is depicted in the Figure 1. In the Figure 1 the needed duration is called the subjective duration and the available duration is called the objective duration.

Sun Tzu (1963) is writing about knowing – among many other things. He claims that the keys to the victory are knowing yourself, knowing the opponent and knowing environs. (Sun Tzu 1963) This is true on temporal dimensions, as well indeed. Knowing subjective time limitations and possibilities, and respective objective ones, gives a decision-maker somewhat good opportunity to choose right moments to put desirably effecting actions in practice.

DECISION-MAKING MODELS

Information providing and timing of information in the national security DSS is studied by the support of existing decision-making models. These models form a good basis to study this topic, because the aim of the national security DSS is to support the decision-makers. Simon presented a model for problem solving, which contains four phases from information and information flows point of view (Figure 2). The phases are: intelligence, design, choice and implementation (Marakas 2002). The model constructed by Simon is good for dealing with a determined problem, however it actually does not include time as an attribute of the overall process, nor does it take time-information relationships into account.

![Figure 2. Simon's model of problem solving (Marakas 2002)](image)

![Figure 3. John Boyd's OODA-loop (Hammond 2001)](image)
Another model to consider is the OODA-loop (Observe, Orient, Decide, Act) as depicted in Figure 3. Developed by John Boyd, a United States Air Force officer who made his career mainly as a fighter pilot, this model is rather deeply analyzed and widely used in western military context (Waltz 1998), (Hammond 2001). Because of his background, Boyd originated his thinking from the arena of air combat, where the battle space is narrowed to the basic fact of killing or being killed. During observation, which is continuous, the environment is perceived, and if something, which should be reacted to emerge, the orientation phase activates. After orientation, a decision is made and an action is implemented.

In addition to decision-making models, information gathering and interpreting is depicted in information management models. Choo (1998) describes an information management cycle that consists of defining information needs, acquiring information and organizing, storing, processing, creating, distributing and using information (Figure 4). The approach of this model is information management in an organization, and how needs will arise from the new challenges. After the information needs are determined, the acquisition process will start in parallel with the storing of the gathered information and transferring of this information to refining process. At the end, distribution of information products and services for information using purposes are completed. (Choo 1998) The model that Choo describes, is purely an information management model, and provides information services and products to, e.g., problem solving or decision-making environments. It does not actually deal with time, but notes about time-divergence of information can be found in Choo’s book.

**SYSTEM MODELS OF THE NATIONAL SECURITY DSS**

A system model of the phases and blocks of the national security decision making is depicted in Figure 5. The model was formed by combining the decision-making and information management models referred in the previous chapter and by adding the human and information and communication technology (ICT) blocks to the figure. The figure uses Soft Systems Methodology (SSM) (Checkland & Holwell 1998) as a structuring tool to express the phases and blocks of national security decision making. The blocks presented in Figure 5 are a human system and an ICT-based decision-support system. The human system contains geographic information and knowledge accumulated in the decision-makers’ minds. Typically, this geographic information and knowledge covers wide range both in space and time. It is about past, current moment or anticipated futures events related to national security. The decision-makers can use spatial and temporal information and knowledge to spatially model and share experiences and anticipations about the past, current and futures events. They acquire the geographic information and knowledge they need both from the outside world and from the geographic database of the ICT-based system. The needed geographic information and knowledge include both basic geographic information about the environment and geographic information and knowledge about the anticipated or realized threats. The basic geographic information include digital terrain model, roads, streets, bridges, buildings, border lines as well as pre-calculated analyses such as shortest routes for vehicles of state authorities. Geographic information and knowledge about threats include objects to be protected such as the main state buildings and online analyses such as effect area analyses of accidents. The ICT-based system contains geographic data and information organization, storage and distribution activities as well as a database consisting of geographic data and information. Geographic data and information in the database only partially overlap with
the geographic information and knowledge in the decision makers’ minds. Observations consisting of location, theme and time data are first stored in the database and then distributed to the decision-makers.

Figure 5. The phases and blocks of the national security decision-making

The human system contains identifying information needs, geographic information acquisition, design, choice and implementation phases. When performing these phases, the aim is to affect the outside world by acting according to the decisions. Acquired geographic information is utilized during the design phase by making analysis such as the effect area analyses of accidents that produces information about the state of the objects to be protected. In addition, geographic information is used for implementing choices, e.g., implementing the decisions concerning the use of resources for protecting the main state buildings.

Kuusisto (2004) presented a general model of the use of information during the design and implementing phases of the decision-making cycle (Figure 6). The model supports the categorizing of information according to the user specific value and updating frequency. It contains three main categories of information: action information, basic information and conclusions as well as information refining steps, i.e., process model. Spatial data are included in all of the categories. Action information and conclusions categories include dynamic spatial data where basic information category includes static spatial data. The model reflects to a state where a comprehensive mutual understanding and sharing of ideas between the decision-makers is provided. The information refining process depicted in the Figure 6 progresses simultaneously on several layers that exchange information with each other. Five different thinking processes occur:

• Finding spatial and non-spatial connections contain those methods that are used for combining the divergent amounts of action data and information together, and with the existing basic information for forming abstractions and conclusions (Kuusisto 2004). Finding spatial connections contains methods that combine dynamic spatial data such as incidents to static spatial data such as information about roads, streets, bridges and buildings.
• Finding confinements contains those methods that are used for analyzing the existing information to find out the limits of possible actions (Kuusisto 2004). An example is spatial analysis, e.g., effect area analysis.
• Finding possibilities contains those methods that are used in a justified way to restrict the impossible courses of action. An example is a comparison (Kuusisto 2004). Spatial information in this process is abstract and about to turn into spatial knowledge. It is used for defining relations between the information contents such as anticipate adversary’s forces movements based on observations about the forces current location and information and knowledge about their possibilities to move.
Finding plausible ways to act contains those methods that produce justified estimates about the probable choices (Kuusisto 2004). An example is war gaming with situational awareness and understanding including understanding about spatial relations in multi-spectrum space and time.

Finding desirable solutions contains those methods that are used for completing the final solution on the basis of presented plausible choices. (Kuusisto 2004) Spatial information and knowledge is included in alternatives to act and used for visualizing the multidimensional data included in the alternatives of act.

The characteristics of the model described in the Figure 6 are:

- Incoming facts are combined to basic information existing on the right level of the system and the refined abstraction about this combination is expressed as the output information, conclusions, on every level. Information is refined top-down. On the first layer, where the number of alternatives is immense the information is only slightly refined. While abstraction increases whole information flows towards the ultimate decision, the amount of possible alternatives decreases. This is the power of the system. The desired ways to act are refined from the huge amount of detailed data in a logical process.

- The model contains three main levels of thinking: the vision level, the strategy level and the operating level. The vision level contains the information and its refining processes that result in making choices to reach the desired future. The strategic level contains those information levels where the anticipation about possible and plausible futures is completed. The operating level contains information that is used to understand and react to the existing world.

- The refining of information can be well supported by technological solutions. (Kuusisto 2004)
When the model depicted in the Figure 6 is applied to the national security decision-making and DSS, the contents of geographic information and knowledge flows for decision support in crisis situations can be formed as sub-contents of action and basic information and conclusion categories. The action data and information categories and examples of the spatial information they contain are the following:

- The situation category consisting
  - the adversary’s resources’ movements,
  - incidents: what, where, when, who are involved, what operations have already been done and
  - security levels of the objects to be protected.
- The environment category consisting of geographic information about the current environment such as whether forecasts. It gives the decision-makers the basis of making assumptions about the objective durations available.
- The resources category consisting of the authorities’ and adversary’s resources, location and response time.
- The means category containing the possible ways to exploit the authorities’ resources.
- The task category containing the tasks given by a higher-level authority.

Geographic information acquisition is based on vision and mission that are included in the basic information category. The other categories included in the basic information are the features category containing basic information about material resources, threat scenarios and characteristics of the threats as well as action patterns category containing, e.g., plans to protect from the threats. In addition, the basic information category contains anticipated futures category consisting of potential strategies such as rapid forces deployment as well as foreseen end-states category containing situations where we end when we and the adversary exploit resources in a certain way. The conclusions consist of the following geographic information and knowledge categories:

- Spatial and temporal model of the situation based on the incoming action data and information combined with basic information. For example, resource data contains routes of adversary’s ships during past ten days. When combined with features category information, the potential influence of the ships is formed.
- Spatial and temporal confinements based on the model of the situation and basic information. For example, the potential influence of ships presented in the model of situation restricts possible activities of our ships located on the influenced area.
- Possibilities to act based on the model of the situation, confinements and basic information.
- Alternatives to act containing anticipations about future situations and resource usage.
- Decision.

The modeling of the contents of geographic information and knowledge flows for decision support in crisis situations as sub-contents of action and basic information and conclusion categories suits the needs of any decision-making levels. However, the detailed contents of the categories depend on the organization and the decision-making level in concern. When this modeling is shared between the state authorities, private companies and interest groups, the model contributes to the co-operation between these units in crisis situations.

A prototype of a DSS based on the model is under development. The aim of the prototype development from geographic information management point of view is to gather end-user feedback about the modeling of geographic information and knowledge flows for decision support in crisis situations as sub-contents of action and basic information and conclusion categories. In addition, the aim is to receive feedback about the technical implementation possibilities of the spatial technology of the national security DSS. The prototype will contain a commercial GIS product suitable for geographic data publishing on the Internet and simple analysis. Especially, the possibilities to manage the time aspect will be studied with the prototype.

CONCLUSION

The situation awareness model referred in this paper provides a new way to approach the decision-making and mission planning process. The model has a knowledge and information perspective to decision-making. When applied to the national security decision-making and DSS, the contents of geographic information and knowledge flows for decision support in crisis situations can be formed as sub-contents of action and basic information and conclusion categories. The categories as abstract object classes suit the needs of any decision-making levels. The contents of the categories depend on the organization and the
decision-making level in concern. A prototype of a DSS based on the model is under development. Experiments of the use of the prototype will be collected during this Spring.

REFERENCES