UTILIZATION OF SPATIAL DATA IN EMERGENCY RESPONSE: SYSTEM OPTIMIZATION BASED ON ANALYSIS OF WORKING PRACTICES

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Abstract
In the area of emergency management, there is immense potential for improvements in utilization of spatial data. Many optimization approaches can be derived from the Digital Earth vision. Experience gained from strategies that will prove useful can consequently enrich the concept of Digital Earth and find their way into other areas of human activities. The paper presents results of research focused on the use of GIS in emergency management. Working practices of fire rescue service operators were analyzed. The analysis revealed many imperfections concerning spatial data availability, accessibility, accuracy, and also methods of data visualization. Results of this analysis were used as the basis for suggestion of possible optimizations in the areas of data visualization, user interface, data use and cooperation. Special attention is paid to geocollaboration as an approach which could significantly improve effectiveness of decision making processes in emergency management.

Keywords: *emergency management, fire rescue service operators, spatial data, geocollaboration*

INTRODUCTION

Digital Earth is a concept that pervades all fields of human activities. It is also true for emergency management – an area, in which digital spatial data (when used properly) help save lives and property. In the Czech Republic, emergency

response is coordinated by regional emergency centers that have to deal with emergency situations occurring in any part of the country. This centralization inherently reduces operators' ability to use their knowledge of local environment and emphasizes requirements for high quality information. Increasing accessibility of various types of digital data can compensate for the missing local knowledge and also bring many other benefits.

An interdisciplinary cooperation of psychologists, database specialists and cartographers was established in order to analyze the needs of various emergency management actors. Their activity was evaluated by methods of direct observation, interview and inquiry. The analysis was focused on using different forms of cartographic visualization of spatial data in the processes of emergency management and revealed many significant weaknesses; its results were used as the basis for formulation of possible improvements in digital spatial data use strategies.

GENERAL APPROACH TO OPTIMIZATION OF GIS AND SPATIAL DATA USE

If any system has to be modified, the first necessary step is to understand it in its current configuration. If this condition is not met, effects of eventual modification can significantly differ from the desired result. Therefore, before any optimization of GIS used in emergency management is suggested, it is necessary to evaluate existing status of the system and also working practices of users and context in which they are applied. The aim is to study behavior closely related to human-computer interaction (HCI); therefore, it is important to draw upon knowledge from specialists in this area, where the appropriate research methods are available. Description of initial status of the system has to be followed by empirical research, which clarifies processes determined by individual items and structure of the entire system consisting not only of GIS, but also of all other technical and personal resources. All findings are analyzed and interpretation of results serves as the basis for modification proposals – optimization. After the suggested changes are implemented, another empirical research has to be performed in order to verify what results were achieved by the optimization process.

EMERGENCY MANAGEMENT AS INFORMATION BEHAVIOR

The goal of the presented research was to describe and analyze variables and processes, which play important roles in emergency management. In some cases, a strictly cartographic point of view is used for studying working practices of fire rescue service operators (or other actors of emergency management processes). In such cases, research is focused on various aspects of the used GIS and all other related processes are seen rather as the environment that to some degree influences methods of using cartographic products. However, from a more general perspective (that of information science), GIS represents only one of many information sources used by operators when dealing with an emergency event. An analysis of emergency management processes that takes this fact into account provides better background for proposing GIS optimization.

When research is focused narrowly on operators' work with GIS and other forms of their information behavior are neglected, valuable information remains unrevealed and distorted picture of the situation may result. Emergency management operators act purposefully when dealing with a situation – they utilize all available information sources in order to increase the effectiveness of their work. Besides formal sources, they sometimes also gather necessary information from alternative, informal sources. Use of informal sources in case the given piece of information is not available from any formal source (or even preference of the informal source when the information is present in both) provides crucial knowledge showing which features of GIS have to be improved in order to better match requirements of users. An analysis of information behavior provides answers for questions „What?" (i.e. what information operators need) and „How?" (i.e. in what form should the information be available and how it should be structured).

Information science

Theoretical background for issues related to information behavior is provided by concepts and models of information science. Information science deals with all forms of collection, storage and retrieval of information. According to Shuman (1992), it may be defined as a science that investigates properties and behavior of information and all aspects of its transfer among both natural and artificial systems. Information behavior can be defined as any behavior related to sources and/or channels of information including information use (Wilson, 2000). Applied research in this area is focused on improvement of information systems based on study of knowledge use in organizations, interactions between people and information systems, and effects of information on people and on artificial systems. Therefore, information science can be seen as a branch of cognitive science.

When applied to the area of emergency management, use of GIS is studied as a specific case of information behavior, during which an information need is satisfied with geographic (spatio-temporal) information. Study of related cognitive aspects also helps to analyze specifics of this process caused by time pressure, which is usually present in emergency

situations. The above-mentioned approach is also based on observations from the area of Geographic Information Science (GIScience). This theoretical approach emerged in the early 1990s as a reaction to the fact, that most GIS research at that time was focused solely on technological issues, and that important cognitive aspects of processing of geographic phenomena were neglected (Goodchild, 1992; Mark, 2000). GIScience also deals with methods of GIS utilization in institutions, role of GIS in decision-making processes, etc.

The above-mentioned development is a part of a broader shift in the area of information science. According to Skrna (2002), since the so-called „cognitive shift" in the mid 1980s users of information systems have been studied not as a group, but rather as individuals with all related aspects forming context of their information behavior. This context consists of all personal, cognitive, situational and system factors that influence the user during search and processing of information. One of the key elements of context is cognitive status of the user that in every moment reflects cognition and thinking of the individual and significantly influences their behavior. Cognitive status is strongly influenced by tiredness, concentration, readiness to perceive information, motivation, emotional aspects of personality, etc. This shift from system centered towards person centered analyses was also reflected in terminology – the formerly used term „system use" was almost completely replaced by „user behavior" (Wilson, 1999; Robins, 2000; Talja and Hartel, 2007).

Influence of time pressure on information behavior was described for example by Niemi and Näätänen (1981) who claim, that time pressure in some situations increases motor readiness leading to quicker reaction when called for, but impedes inhibition processes, which increases the risk of premature responses. These results were confirmed also by Osman et al. (2000) and Sangals et al. (2004).

Interactive information retrieval and information behavior models

Overall character and working practices of fire rescue service operators can be described with the use of a theoretical approach called interactive information retrieval. In this approach, the iterative nature of information searching is stressed (Robins, 2000). Principal study methods of this approach include observation of users in natural settings, discourse analysis, and other protocol analyses such as think aloud protocols. Belkin et al. (2009) also emphasize dynamic nature of information retrieval. They claim, that any research must „explicitly include users, tasks, and contexts in a dynamic setting rather than treating information search as static or as a sequence of unrelated events". In addition to that, Fuhr (2008) analyzes probability aspects of information behavior.

Structure of information behavior can be described with the use of models, which can serve as a frame for analysis of the selected activity. Several models of information seeking and other aspects of information behavior were presented and evaluated by Wilson (1999). They deal with the relationship between communication and information behavior in general and also describe information seeking and information searching in information retrieval systems. The author also presents his own model of information behavior (see Fig. 1).

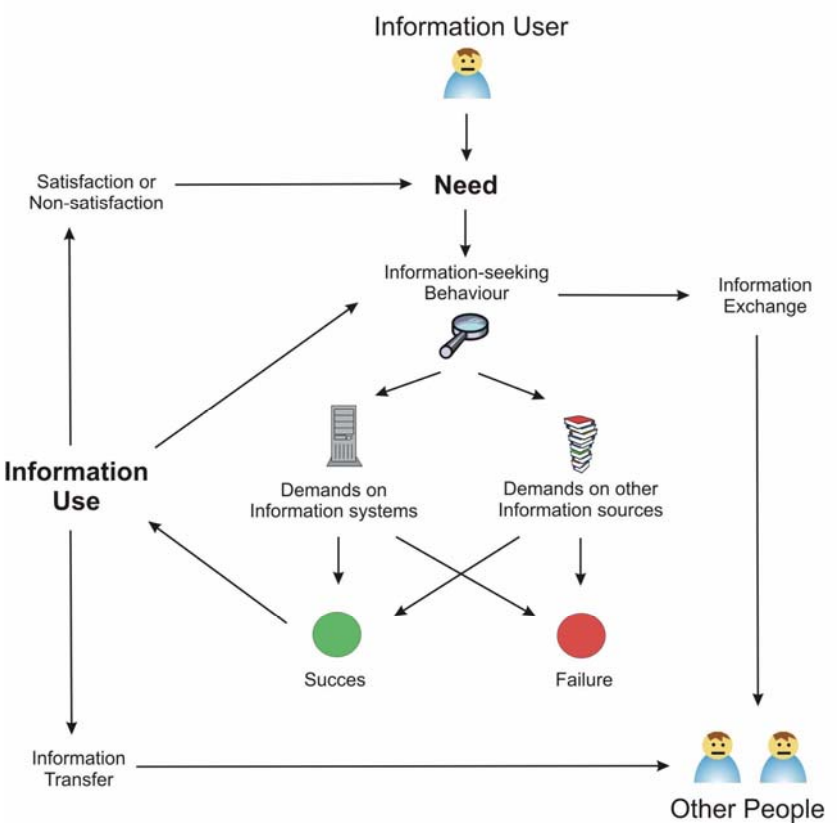

Figure 1. Wilson's information behavior model (adopted from Wilson, 1999)

Wilson (2000) also expands a model developed earlier by Dervin (Dervin, 1983; Savolainen, 1993) of the so-called „sense-making approach". This model shows relations among four constituent elements: a situation in time and space, which defines the context in which information problems arise; a gap, which identifies the difference between the contextual situation and the desired situation (e.g. uncertainty); an outcome, i.e. consequences of the sense-making process; and a bridge, i.e. some means of closing the gap between situation and outcome (see Fig. 2).

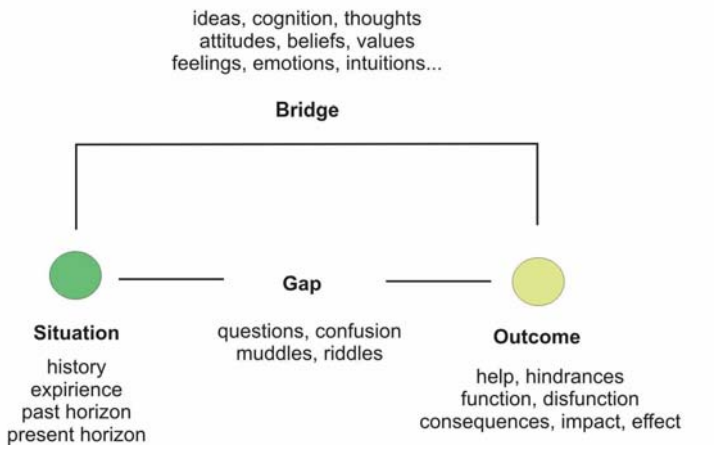

Figure 2. Modified Dervin's sense-making model (adopted from Wilson, 1999)

RESEARCH METHODS

Research presented in this paper is based on theoretical principles described in the previous chapter. Attention was paid to the entire scale of information behavior of operators, in which use of GIS represents only one of performed actions. Aspects that were observed include interindividual differences, working environment, structure of the organization, and also influence of time pressure on information behavior of operators. Special emphasis was placed on ecological validity (i.e. the degree to which behaviors observed in a research study reflect behaviors that actually occur in natural

settings). Qualitative methodology was used for the research – research data was continuously analyzed, research categories were created, revised, and modified in the entire process of data collecting. Acquired data was processed by methods of quantitative content analysis.

Observation and parallel unstructured interviews (recorded to an audio device) with operators of the fire rescue service were used to gather data. First part of this research took place in a training centre of the Fire Rescue Service of the Czech Republic, where beginner operators are trained and gain experience with utilization of GIS during simulated emergency events. Resulting data was analyzed and – together with other available documents such as internal directives and regulations of the fire rescue service – served as the basis for determination of the most important issues that were consequently examined in detail during interviews with operators of Regional Operation and Information Centres of the Fire Rescue Service in Brno and in Ostrava. These two centres were selected because the basic concept of their organizational structure is different, which also influences methods of dealing with emergency events. Therefore, a comparison allows better understanding of emergency management processes. A total of 18 subjects were studied (10 males, 8 females; age 26-63 years). Recordings of telephone calls to the emergency line 112 were also analyzed.

Observation was primarily focused on utilization of spatial data (mainly GIS) for management of emergency events. Inquiries were made immediately after an event was processed. Basic observed and analyzed unit was the reception and processing of one emergency call. Attention was also paid to spatial arrangement of emergency centres, all communication channels and information resources that operators use for their work.

RESEARCH RESULTS

In order to deal successfully with an emergency event, the operator who answers the incoming call must be able to mine as much incoming information as possible. This information is used to determine type and location of the emergency event. Depending on type and extent of the situation, it is decided who will deal with the incident (fire rescue service, police, emergency medical service) and how many units will be dispatched. Individual emergency units may depart from different locations, and therefore in some cases approach the incident site from different directions. Getting correct initial information about the incident is crucial for selecting suitable solution of the situation.

For initial localization of an emergency event and for consequent operation management, most spatial information is derived from GIS and audio reports from intervening units. In all regions of the Czech Republic (with one exception), the operator answering an emergency call uses GIS for localization and a special application for sending all available information (type of event, verbal description, localization, contact information of the caller) in a structured XML document called “data sentence” to all organizations that were selected to intervene (fire rescue service, police, and/or emergency medical service). However, these organizations use different geographic information systems. Within the fire rescue service, two GIS systems are used: one is used by operators answering emergency calls and another one used by operators controlling intervening units. Both systems are connected only unilaterally by data sentence; therefore, in case the emergency call operators receive additional information when the intervention is already in progress, they are not able to communicate it via the system. The only possibility is face-to-face communication with fire brigade operators or audio communication with police and/or emergency medical service operators.

The main difference between the two above-mentioned geographic information systems is in the way they are created, administered, and updated. GIS for emergency call operators is created centrally for the entire Czech Republic, is administered by a private company, and updates are applied only after the necessary information is gathered from all regions. Therefore, in case changes in a data layer are detected in one region, updating is not performed instantly, but only after the data layer is updated in all other regions. This process is often time consuming and may negatively influence effectiveness of emergency call operators’ performance and correctness of event localization. Moreover, the form of visualization of some data layers is unsuitable (operators complained for example about points of interest being visualized by colored areal symbols).

On the other hand, GIS for operation control of fire brigade units is administered locally in every region, which means the database is updated more often and better suits requirements of workers who use it. Therefore, this system has much richer content and includes information, which in many cases would be useful also for emergency call operators. At the same time, more attention is paid to selection of proper visualization of data in this system.

As a result, emergency call operators are often forced to search for required information outside their GIS, for example on the Internet, in printed maps, and in some cases even in self-made lists of information not present in GIS (for example names and telephone numbers of gas stations, shopping centres, banks, etc.). They also often consult co-workers who have better knowledge of the concerned area.

It is clear, that in order to solve an emergency event effectively, all involved actors have to cooperate. Localization of an incident and consequent coordinated intervention are linked activities, during which each participant moves solution of the event by one step. Therefore, attention has to be paid not only to problem processing performed by individual actors, but also to the process of transmission between actors, during which all relevant information must be transferred in a complete and undistorted way. However, in some cases the number of actors (operators, intervening units, etc.) is relatively high and coordination of all parallel efforts is demanding. Obstacles can arise both from personal and technical issues. For example, when an incident occurs near the state boundary, operators have to deal with the fact, that data used in GIS are not available for any area outside the Czech Republic. It is clear, that availability of data from GIS of neighboring countries would increase effectiveness of interventions in these areas.

Other specific problems mentioned by interviewed operators include the following:

- it is not possible to set and save settings of thematic data layers, desktop arrangement and GIS tools settings for individual operators (i.e. missing personal user profiles)
- inconvenient user interface
- long response time of GIS (due to hardware and/or connection problems)
- unpreparedness of the system for iterative nature of problem solving (e.g. in case of critical incidents operators dispatch units immediately after they make approximate localization; exact localization is performed when units are already on their way. However, transfer of refined information to units in the field is complicated and only audio channels are available for it)
- requirements on type of data visualized in map strongly differ depending on type of situation, i.e. different maps should be displayed automatically according to context (type, extent of incident, etc.)

PROPOSALS FOR OPTIMIZATION

Results presented in the previous chapter served as the basis for suggesting several optimizations related to use of spatial data in emergency management. Cartographic support of decision making process can be improved by addressing issues in the following domains:

- user and situation oriented visualization optimization
- interface optimization
- data use optimization
- optimization of cooperation (geocollaboration)

User and situation oriented visualization optimization

One of the possible ways of cartographic visualization modification based on user demands is application of principles of adaptive contextual cartography. This approach is described foe example by Konecny et al. (2006). Three basic methods are used for optimization of visualization: change of symbolics, generalization and change of visualization method (cartographic method).

Adaptive contextual visualization can be used both for addressing problems related to personal settings with preferences of individual users and to displaying different data layers for different types of incidents

Interface optimization

User interface is one of the most important aspects which can possibly influence quality of decision making processes. The presented results have shown that fire rescue service operators would prefer an interface that would be more user-friendly (especially controls related to search tools and other spatial operations).

Data use optimization

Optimization of utilization of existing data sets involves better connectivity among different databases and also improvements in the process of updating. An advantage of emergency management (compared to other fields where spatial data are frequently used) is the fact, that legal regulations strongly favor access to all necessary data (both public and private) free of charge.

Other issues that have to be dealt with is utilization of non-spatial data and tools (e.g. conference talks during the decision making processes, availability of records of all former calls, etc.), use of existing web services, web cameras,

sensor networks (e.g. meteorological) etc., and also an option of creating new, unofficial datasets with necessary information.

Optimization of cooperation (Geocollaboration)

Cooperation during intervention can take place either in the same place (cooperation of operators during localization, cooperation of fire rescue service, police and emergency medicals service at the site of an accident) or in different places (for example cooperation of operator with units in the field). In the latter case, effectiveness of intervention could be increased by implementing tools allowing geocollaboration. According to MacEachren et al. (2006), the main principle of geocollaboration is cooperation of two or more people/units, who can be in different locations, solving simultaneously a spatial problem with the use of spatial information and information technologies.

In the area of emergency management, connectivity and compatibility of various GIS systems used by different units has to be provided. Currently, communication channels are represented mainly by audio communication tools and data sentence (structured XML document). However, effective use of spatial data requires access of all actors to all databases (with the possibility of data editing where appropriate), dynamic visualization, etc.

Many methods and tools used for geocollaboration are currently developed and their introduction in the area of emergency management will bring a significant improvement in decision-making processes and the overall effectiveness of emergency response.

CONCLUSIONS

The paper presents research focused on use of spatial data in emergency management. Working practices of fire rescue service operators were analyzed. The analysis revealed many imperfections concerning spatial data availability, accessibility, accuracy, and also methods of data visualization. Results of this analysis were used as the basis for suggestion of possible optimizations.

The authors suggest that selection of visualization tools and methods should be more user and situation oriented. Introduction of principles of adaptive contextual visualization could be a suitable way of dealing with this problem. Other optimizations were suggested in the areas of user interface and data use. Major improvement of decision making processes in emergency management could also be provided by implementation of methods and tools of geocollaboration.

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