The Effect of a Geographical Information System on Communication in Professional Emergency Response Organizations

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ABSTRACT

This paper describes the basic communication analysis performed in a research project with an ambition to investigate the impact of geographical information system (GIS) on crisis management organizations. The goal is to compare the communication between command and control teams that have access to a GIS with geographical position information (GPS) capability in its command post with teams that only have access to paper maps. The method used is controlled experiments using the C3Fire micro-world. A total of 108 professionals, forming 18 teams, participated in the study. The participating professionals were members of Swedish municipal crisis management organizations. The result shows that the communication pattern connected to giving orders have a different distribution depending on if the teams used GIS or paper maps. The result also shows that the communication volume is reduced if the teams use GIS.

Keywords

Geographical information systems, command and control, emergency response, micro-world simulations.

INTRODUCTION

The research question, upon which this paper leans, is how collaboration, communication and work processes in crises management depend on the type of support that is supplied to a crises management team. The main motive is to gain knowledge on how the communication within crisis management teams differs depending on if they have decision support in form of a geographical information system (GIS) with geographical position information (GPS) unit positioning or if they only have regular paper maps. The organization of interest is the Swedish municipal organizations and their crisis management teams. An experiment was conducted were 18 Swedish municipal crisis management teams, a total of 108 professionals, participated. GIS with GPS based real time unit positioning are increasingly common in the rescue service organizations in Sweden.

Background

Sweden is structured into 21 regions and 290 municipals. The main responsibility for crisis and emergency response lay upon the municipals and their rescue service. The general idea is that a crisis or emergency shall be handled where it occurs. The kind of crises this research is set for is on the level where both the rescue service and the municipal crisis administration become involved and need to collaborate. This could for instance be a dramatic storm, landslide, chemical spill, bigger power cuts, floods, larger fires or a combination of events like these. One similarity of these events is their bond to geospatial information, and the possibility to expose this information in GIS.

Currently, many of the municipalities have made, or are about to make, investments in information and communication technologies (ICT), such as GIS, with the goal of increasing performance and control in their

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work. With this new technology groups of heterogeneous professionals shall form functional teams that need to be able to handle the multidimensional data in ICT and GIS. (Laurini and Thompson, 1996; Bernhardsen, 1999; Maguire et al., 1991). In time these systems will be indispensable tools in modern emergency response operations (Mendonça et al., 2001), but at the moment they are novel.

Scientific communities such as computer supported cooperative work (Schmidt and Bannon, 1992), distributed cognition (Hutchins, 1995) and cognitive systems engineering (Hollnagel and Woods, 2005) have all emphasized the importance of studying actual use of new ICT tools in practice, rather than to draw conclusions from hypothetical gains of new technology. In this paper, we utilize a combination of a low-fidelity simulation and professional participants in order to investigate if decision makers really benefit from new technologies, and how their work is affected by such technologies.

Our question is how the support that GIS offers influence the way the commanding officers communicate with their subordinates. Earlier studies with non-professional participants have shown how non-professionals give orders to their subordinates, in form of mission tactics, or direct control, and how well their command teams perform. (see Johansson et al, 2007). There are however several studies that indicate that such results not easily can be transferred to professional users (see for example Rogalski 1999; Johansson, Granlund & Waern, 2005). This motivates the study presented in this paper, where professional participants are involved as a complement to prior finding based on research on student (non-professional) participants.

METHOD

The core of the method is controlled experiments in a micro-world simulation. (Brehmer and Dörner, 1993; Granlund, 2002; Gonzalez et al., 2005, Howie et al., 1995; Rolo et al.2001). The experiment series is performed with the simulation environment C3Fire. In the experiment series the participant experience a set of scenarios, where an emergency response task is simulated. The goal of the scenarios is to make it possible to study work processes, on an operational level of command, associated to the usage of GIS or paper based maps. The domain in the emergency response task is command and control in forest fire fighting.

The C3Fire Simulation Environment

The C3Fire simulation environment (www.c3fire.org, Granlund, 2001; Granlund, 2002; Granlund & Johansson, 2003) is specifically designed for command and control studies. C3Fire generates a dynamic forest fire fighting task with characteristics similar to those people normally encounter in real-life situations. The system allows controlled studies of collaboration, decision-making, cultural differences in teamwork and effects concerning information communication tools in command and control (Granlund, 2004, Lindgren & Smith, 2006a, 2006b, Johansson et al., 2003, 2005).

GIS module:

For this study a GIS module with capabilities corresponding to present GIS-like information in command and control applications was connected to C3Fire. The module includes GI visualization, GIS functionality and map input features. It is possible to swap between map layers as topographical, orthophoto, and land use maps. The functionality also included unit positioning in real time, similar to real-world systems based on GPS technology. The users could thus see all own units and their exact positions in real time. This functionality is to day available in most modern emergency management solutions in Sweden.

Scenario:

During the five simulation trials of an experiment, three forest fires start on different places. The location of the fires is different in each trial, but the same for all the 18 teams. Each trial is also defined with a scenario. The scenario contains information about wind direction and its strength as well as messages, which are sent to the participants to help them create an understanding of the situation. The design of the scenarios is made in such a way that it creates interesting situations to study.

Data Collection:

All actions taking part in the simulation is logged into a database. All email communication between the crisis managers in the command post and the ground chiefs is logged into a database. All communication between the crisis management is recorded with cameras. All communication in the after action reviews are also recorded.

For this paper it is the emails communication sent between the command post and the ground chiefs that are analyzed. Email is the only communication between the command post and the ground chiefs. The logged email data includes sent information, sender, receiver and time when the emails were sent, received and opened.

Experimental design

The study is a between-group design with one factor: (a) crisis management teams using GIS, and (b) crisis management teams using paper maps, see figure 1. The difference between the two conditions is the type of support the participants obtain in terms of information visualization and data sources. Nine participant groups were tested in each condition, giving a total of 18 participant groups consisting of six persons, summing up to 108 participants. The participants were municipal crisis organization members.

In each team, three participants work as crisis managers in a command post and three participants work as ground chiefs (figure 1). The crisis management team consists of one commanding officer and two communication officers. They work on a tactical level and command the ground chiefs. The crisis managers have no direct contact with the simulation and only control the simulated world indirect via the ground chiefs. The ground chiefs control three units (fire brigades) each in the simulation.

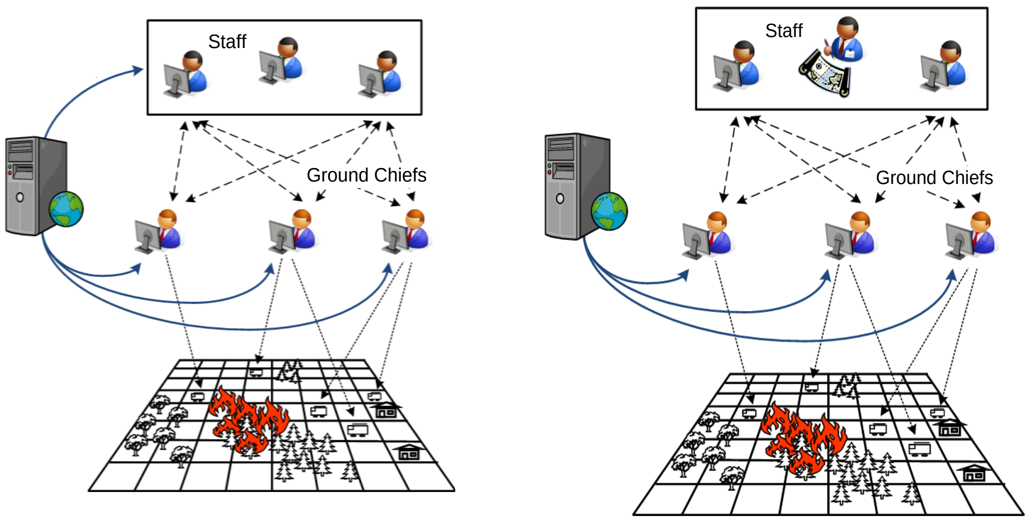

Figure 1. GIS condition and paper map condition

The GIS condition:

In the GIS condition the commanding officer have access to a computer terminal equipped with a GIS. The GIS provides access to different digital map layers containing geographical information and GPS of the resources, units, in the field. The two communication officers have computer terminals that provide communication with the ground chiefs in terms of e-mails.

The GIS provide them with precise and accurate real-time data that are generated in the organisations information system. Their task is to manage the technology and to use this information in such a way that the units can be coordinated efficiently in their task of extinguishing the forest fire.

The paper map condition:

In the paper map condition the crisis management team has no access to a GIS. Teams using paper map need to acquire knowledge about the state of the forest fire and fire brigade positions by communicating with their ground chiefs. The paper map requires no technical competence in terms of computer skills.

The crisis management team has custom-made paper-based maps available. Besides the paper-based maps, the two communication officers have computer terminals that support communication with the ground chiefs.

Ground chiefs:

In both conditions, the ground chiefs have access to a computer terminal with a single layer digital map and a communication tool that makes it possible to communicate with the command post.

Experimental procedure

The experiment is performed in four basics steps, introduction to C3Fire, hands on training, five session cycles and a concluding debriefing (figure 2).

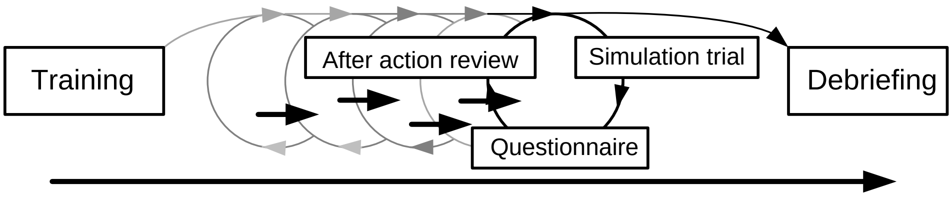

Figure 2. The experiment procedure with; training, five session cycles and a concluding debriefing.

The training consists of instructions and a 15 minutes simulation trial, followed by time for making questions to the instructor and time to do some mission preparing discussion in the team. After the introduction five experimental session cycles follows. The activities of each cycle are 20 minutes C3Fire simulation trial, 10 minutes of individual questionnaires (personal reflection) and 10-20 minutes after action review were the whole group is active (joint reflection). The debriefing discussion underline the participants awareness of processes that they have achieved during the whole set of trials. This concluding debriefing should reflect the whole day and should bee seen in contrast to the after action reviews that focus on performance taking place in every cycle in the five cycles. The whole experiment procedure takes about 6-7 hours, with pauses included.

RESULTS

The results below are mainly from the fifth simulation trial of the experiments. If not so it will clearly be declared. At the fifth trials the teams have had opportunity to gain expertise, mutual understanding about the task and mutual communication strategies. The communication content results are only from analyses of the text messages send between command post and ground chiefs in the fifth simulation trial.

Communication content

The emails sent between the command post and the ground-chiefs have been categorized in accordance with a coding-scheme in to four main categories; question, information, order, and other. These four main categories are in turn divided into 11 sub categories (figure 3). The 11 sub categories are mostly self-explanatory. However, the distinction between the two different types of “Order” needs clarification. Mission order is an order with a high degree of freedom, for instance “fight the fire west of the town”. Direct order is an order with a low degree of freedom and a high degree precision, which leaves little room for own initiative, for instance “go to pos 54, 48”. The categories are based on categories done by Svenmarck & Brehmer (1991), but they have been modified to fit the scenario used in this study.

Question		Information			Order		Other			
1	2	3	4	5	6	7	8	9	10	11
About Fire	About other persons activity	About Fire	About own activity	About other persons activity	Mission order	Direct order	Request for help	Request for clari-fication	Acknow-ledgment on info or order	Misc-ellaneous

Figure 3. Four main communication categories and 11 subcategories.

Two independent judges trained in using the coding scheme performed the coding of the emails. The judges reached an inter-rater reliability of .89 (calculated with Cohen's Kappa). The result of the email classification can be seen in table1 and figure 4.

		Question		Information			Order		Other				
		1	2	3	4	5	6	7	8	9	10	11	Total
GIS	average	1	2	8	5	1	4	9	0	1	8	5	44
	%	3	5	17	12	3	8	20	0	2	19	11	100
MAP	average	2	5	9	12	2	5	6	1	1	8	5	56
	%	4	8	16	22	4	8	10	2	2	15	8	100

Table 1. Average amount messages in each category, and percentage of three highest ranked categories.

The values that differ most between the GIS and Paper map conditions are categories, *Information about own activity (4)* and *Direct order (7)*. The three most emphasized categories in the GIS condition are *Information about the fire (3)*, *Direct order (7)* and *Acknowledgment on info or order (10)*. Very few of the text messages in the GIS condition were Q*uestions (1, 2)*. The three most emphasized categories in the paper map condition are *Information about fire (3)* and *Information about own activity (4)*, and *Acknowledgment on info or order (10)*.

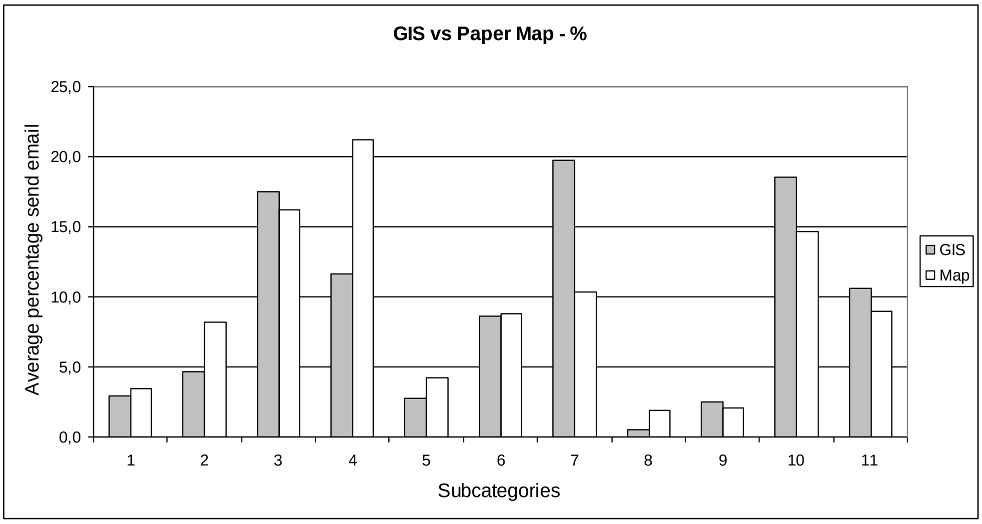

Figure 4. Four main communication categories and 11 subcategories

Looking at average and percentage gives an indication on the similarity between the two sets of communication. Beside the similarity there are only two things we want to highlight, *Information about own activity (4)*, and *Order (6, 7)*. Subcategory 4 is the only subcategory that shows a significant difference, $t(16) = 4.87$, $p < .001$, between the amounts of messages sent in the GIS condition compared to the paper map condition.

The Order categories (6, 7) are interesting. A significant difference, t(16) = 4.06, p < .001, between direct order and mission order can be found within the GIS condition, but not within the paper map condition (figure 5).

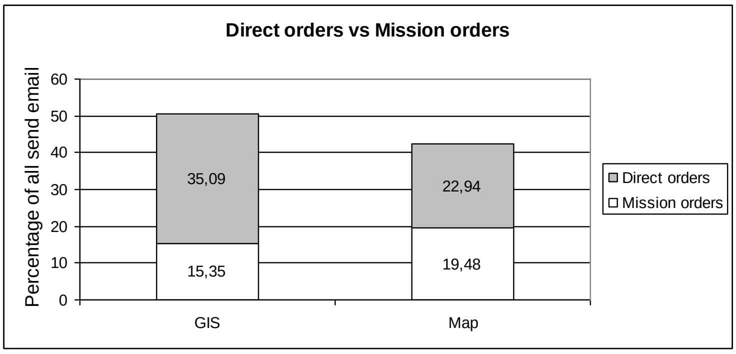

Figure 5. Direct order vs. Mission orders

Sender dependent classification:

The communication patterns can be made more visible by analyzing it depending on who the sender is.

In figure 6 are the communication categories for the messages send from the command post to the ground chiefs visualized. The basic observation is that command posts in the GIS condition mostly send *Direct orders (7), Mission order (6)* and *Info about the fire(3)* to their ground chiefs. The command posts in the paper map condition mostly send *Direct orders (7), Mission order (6)* and *Questions about others activity (2)* and not *information (3, 4, 5)* to their ground chiefs.

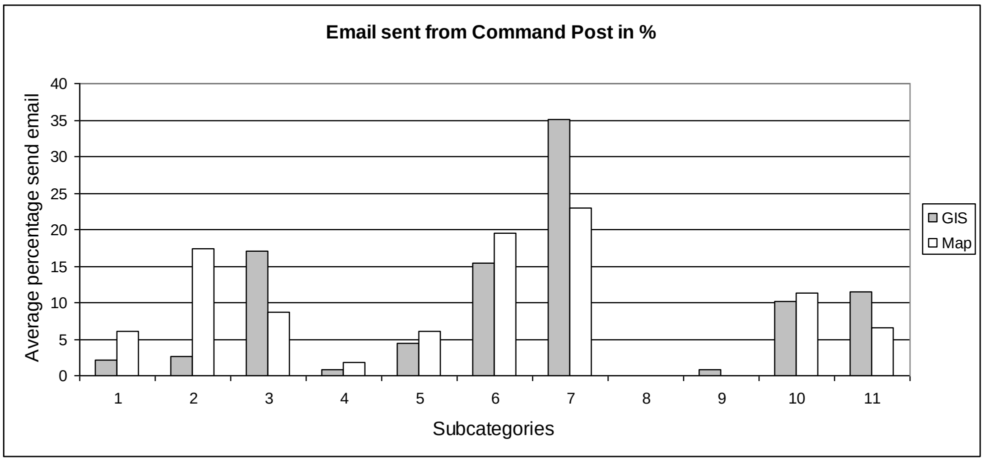

Figure 6. Communication categories for emails sent from the Command Post

In figure 7 are the communication categories for the messages send from the ground chiefs to the command post visualized. The basic observation are that ground chiefs in the GIS condition mostly send *Acknowledgement on order or info (10)* , *Info about own activity* (4) and *Info about fire (3)* as do the ground chiefs in the paper map condition.

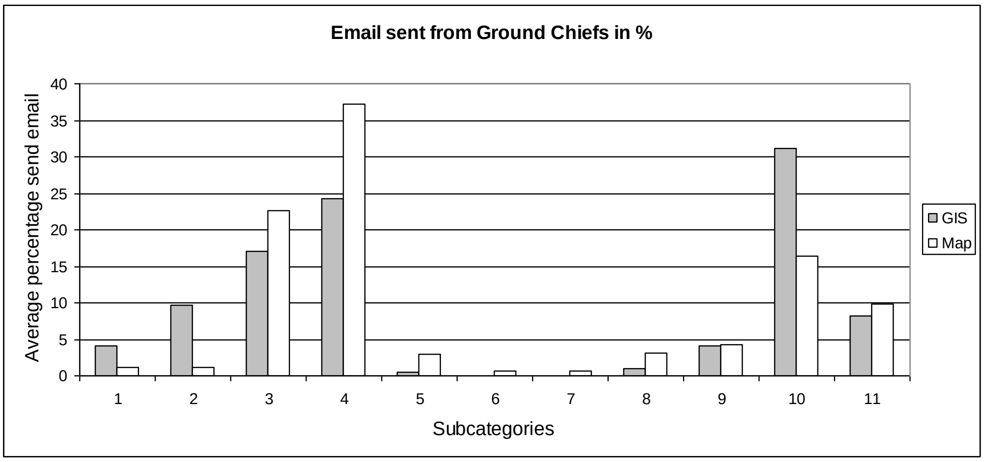

Figure 7. Communication categories for emails sent from the Ground Chiefs

Communication volume

An other way of comparing the communication between our two conditions is to compare the amount of messages sent between the command post and ground chiefs. Figure 8 views the amount of email sent in the five simulation trials.

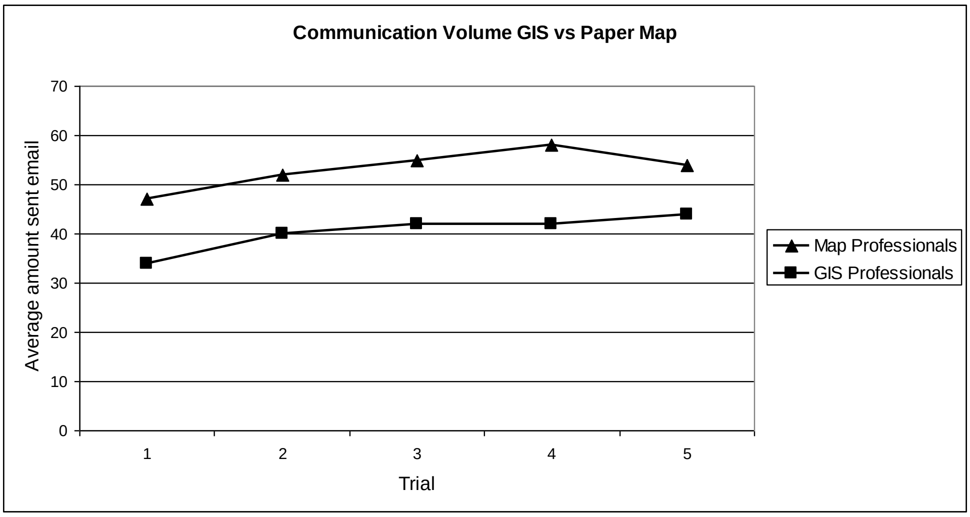

Figure 8. Average amount of email for the five simulation trials

The five trials taken all together gives a significant difference, t (108)=6,46, p<.001, in the amount of emails sent between command post and ground chiefs, and imply that the participants in the GIS condition to some extent reduce the communication in their work.

There is no significant difference in the amount of emails sent between command post and ground chiefs in the fifth simulation trial of the experiments. The average amount email sent in the GIS condition is 44.11, about 2 emails per minute. The average amount of email sent in the paper map condition is 55.25, about 3 emails per minute.

Communication ratio

In traditional one-to-one communication in command and control operations the ratio between sent and received messages is approximately 1:1 (Trnka et al, 2006).

The ratio of text messages sent and received from the perspective of the command post is 1:1 in the GIS condition. The commanders send 1 text message to a ground chief and received 1 text message in return. The ratio of emails sent and received from the perspective of the command post in the paper map condition is 1:2. In this condition the commanders send 1 text message to a ground chief and received about 2 text messages in return. See table 2.

Professional	Command Post Sent		Command Post Received
GIS	1	:	1
Paper map	1	:	2

Table 2. Professionals ratio of messages sent and received from the perspective of the command post.

DISCUSSION

The set up of the experiment series assumes that the fifth simulation trial is the most important from communication pattern perspective. At this trial the participants has gained individual expertise and mutual understanding of the task. The participant group has as far as possible had opportunity to become a team. The learning curves that often occur in this type of experiment have equilibrated. The assumed communication strategies have had time to take form and become stabilized.

The communication content analyze on data from the fifth trial includes two elements to consider, communication pattern within the conditions based on the analyzed categories and communication patterns between the conditions.

Within Conditions:

The first consideration is the communication patterns within the two conditions, GIS and paper map. The content of the communication of the fifth simulation trial was divided into four main categories, *Questions*, *Information*, *Order* and *Other*. On the category *Order* we expected that a GIS, with its detailed representation of data, could alter the order giving in favor for increased *Direct order* (7). This seems to be the case. Within the GIS condition there is significantly more *Direct orders* (7) given than *Mission orders* (6). This is an effect that we want to highlight as one of the pitfalls of GIS. The GIS does not filter data given to the command post in the manner that person-to-person information does. All data including irrelevant and too detailed data is given in real time to the command post. The decision maker is deceived to give commands with a high degree of precision. This leaves subordinate decision makers with little freedom to take own initiatives depending on his/hers own assessment on needed actions.

On the main category *Order* within the paper map condition there is no significant difference between given *Direct order* (7) and given *Mission order* (6). This could be a consequence of the natural filtering of information represented in this condition. The data given to the command post is filtered through the person-to-person information chain. The decisions of the command post are on a strategic level and leave subordinate decision makers with a high degree of freedom to take own initiatives.

Between Conditions:

The second consideration is the communication patterns between the two conditions. The four main communication categories were divided into 11 subcategories. Of these only category four, *Information about own activity* (3), show a significant difference. The ground chiefs of the GIS condition send less information about their activities to their command post than the ground chiefs in the paper map condition. This is a consequence of the GIS ability to visualize data and an advantage of GIS.

Beside the *Information about own activity* (3) the communication category *Acknowledgement on order or info* (10) shows some differences. See figure 7. The differences in the number of acknowledgement send from the ground chiefs in the GIS respective the paper map condition can be explained with the following. In the paper map condition the command post send questions to their subordinate ground chiefs. The ground chiefs respond with information on these questions. The information itself is a form of acknowledgement as consequence the need for pure acknowledgement is lesser. In the GIS condition the command post send a lot of orders to the ground chiefs. The ground chiefs respond with acknowledgement on these orders. Their amount of pure acknowledgement is greater.

Another observation is that as the command post in the GIS condition sends relatively many *Direct orders* (7). These orders are not enough to create an understanding of the mission; the ground chiefs then need to add questions on order to deepen their understanding on what is going on. This can explain the larger amount of question send in the GIS condition for ground chiefs.

CONCLUSIONS

The original proposition of this paper was that the digital and detailed representation of reality that a GIS provides, compared to a paper map, is likely to influence the communication of professionals during a collaborative emergency response task. To summarize the findings following conclusions can be drawn.

- *GIS encourage an increased direct command* – Command teams using GIS exchanged significantly more direct commands than mission commands. The commanding officers in the GIS teams had real-time, easy accessed and detailed information about what was going on in the field and had thus an opportunity to issue direct commands concerning the specific fire-brigades actions in the field and overstep the ground chiefs' initiative.
- *Communication volume* - The result suggests that GIS might reduce the need for communication, mainly in the area of transferring information. Command teams using GIS exchanged significantly fewer messages that command teams using paper-based maps. But there is no significant difference of the volume in the fifth simulation trial. The commanding officers in the GIS teams could see what was going on in the field and had thus less need for information concerning position of the fire-brigades and the fire outbreak.
- *Communication ratio* – The result indicates that professionals using GIS balance the communication so that the ratio is 1:1. One sent message for every received message. While the professionals in the paper map condition have a communication ratio of 1 to 2 from the perspective of the command post. The ground chiefs have to send 2 messages for every received message. This is due to the command post need for information

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