D2.2
HF-based design inputs to COPE technology - Conceptual and empirical considerations of Common Operational Picture

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Abbreviations

ConOps	Concept of Operations
COP	Common Operational Picture
COPE	Common Operational Picture Exploitation (project name)
CROP	Common Relevant Operational Picture
CTP	Common Tactical Picture
ER	Emergency Response
ERC	Emergency Response Centre
ESC	Emergency Services College
SA	Situation Awareness
TETRA	TErrestrial Trunked RAdio, digital mobile telephone system that supports both speech and information transmission; used nationwide in Finland by all public authorities working in the field
WSN	Wireless Sensor Network

1 Introduction

The purpose of this document is to facilitate the project's comprehension of the Common Operational Picture (COP) which is the central concept of the project. Improving COP and providing technology to support COP is the aimed outcome of the project. Earlier attempts to define the concepts were reported in the Annex 1, Human Factors White paper, the D.2.1. In this report we draw on the ideas expressed in these documents. We make an attempt to elaborate and concretise them by consulting relevant conceptual definitions in the literature, by interviewing fire fighters about their experiences in the field, and by analysing empirically the COP as it appears in the current first responder practice, while exploiting the currently available tools. The current practice was captured in a field study in Kuopio Finland which focused on a particular fire fighting incident involving a car accident with large ammonium leakage. In order to be able to foresee how COP could be formed in the future, the researchers made an intervention to the present practice in the form of a "design study". A new type of test arrangement was developed to observe the future COP. According to this arrangement, we tried to simulate a new practice parallel to the on-going present ER practice. Concerning the new practice, the purpose was to estimate the added value that Wireless Sensor Network (WSN) technologies could bring to emergency response in fighting hazardous substances. The present practice was meant to create a background that would facilitate identifying the possibilities to develop the practice. The different conceptual and empirical work accomplished by VTT, BAE, ESC and UTI are described in the report. We also make conclusions that are hoped to be helpful in the development of COPE technologies during the project.

2 Conceptual basis for Common Operational Picture (COP)

2.1 Background for the concept of COP

There is no single definition of Common Operating/Operational Picture (COP) in the literature.
The first mention of Common Operating (or Operational) Picture on the web is as part of an envisioned technology interoperability program where a COP is a result of a Common Operating Environment (COE). COE in turn refers to an integrated information architecture infrastructure for the US military that supports interoperability of technology systems. Hence, the origin of the concept of COP is not in human-technology work systems but in the beginning, it was a consequence of a specific technical design (DII COE, 1998, 2000a & 2000b).

Following disagreement in the US military and R&D community about the relevance of a generic COP to military commanders and military teams, the term CROP (Common Relevant Operational Picture) appeared briefly in order to identify that not all information was relevant to all actors in the operational environment and that information should be presented in a way that was relevant to different user groups (with different operational tasks and goals). A subset of the COP was the CTP which is a Common Tactical Picture, but this term is not in wide use as far as we can tell from web searches and interacting with military technology developers.

Hence, COP became a technology driven concept, where the goal was to provide common information and data exchange formats between different systems and software. This bled over into information presentation to military users who had to work in large organizations and teams. The concept was that if everyone had the same data on the screen in front of them, then they would all share the same understanding of the situation (shared situational awareness).

One perspective on this search for the term COP is that it is in fact a technology term that refers to systems that can share information and share that information across multiple actors, that COP is, by definition, a technological solution. Our stance in this case is that COP as defined above is not the appropriate way to support the coordination of shared understanding and coordinated action in emergency operations. We need to move beyond this COP concept in ER, formulate it anew so that it could provide a conceptual background for defining, through a usage-driven approach, the appropriate technologies and representations/interfaces that support ER incident command.

2.1.1 COP – in the technology, in the head, or somewhere in between?

In this COPE project, COP has been preliminary defined as something that emerges between data/information that is received by an actor, the implications that that information has to that actor for how he should act in the operational environment. A key challenge is that different actors have different goals and different interpretations of information with respect to their action capabilities (different affordances are perceived) and thus even though the data presented on a screen may be common to all, the "operating picture" is dependent on the subsequent "cognition" (perception and processing) that occur with each actor. One purpose of COP is to try to make people's understanding of situations/operational environments explicit in order to promote coordinated action and especially "coordinated" (common) anticipation/expectations about how the situation will evolve given the actions of all the actors on that environment (i.e. for generating expectancies about how the situation will evolve which will impact what actors do). In an operational C2 environment, the most important perspective on the situation which needs to be made explicit is the interpretation of the situation of the incident commander and the rationale for tasking, objectives and priorities.

COP should include data from sensors, including technology and human sensors, and should allow for the interpretation of those data by commanders to be represented, so that subordinates can adjust their actions to fit the plan and intent of the commander. As alternative interpretations of the situation (maybe due to better local information) may exist, these alternative interpretations and the implications for action should also be made explicit where possible as it is needed for coordinated action.

The Common Operational Picture emerges from the intersection of data/information, knowledge/experience, emergency response demands and commander's intended response to those demands (objectives and priorities), and the technology that represents these to various actors. It is not data and technology alone (i.e. common data formats, common data displays of sensor information, everyone sees the same display elements). The data and technology support, rather than define, the COP.

The function of the COP is to support common understanding of the emergency demands and the coordination of the actions of various actors in response to those demands.

Currently, the operating picture at the incident ground seems to be mainly in the heads of the various emergency service actors. The only information that might be represented as a COP are the Command Wallet/Incident Command Board or the Incident Command drawings/maps etc captured on white boards at the Incident Command Point. The reason why this is notionally the COP is that it is not clear that this information is ever shared beyond the immediate command group dealing with the incident or beyond the oncoming command group that assume command at a hand over.

2.1.2 Related Human Factors Concepts

Shared understanding in collaborative work has been approached from several different perspectives in the research literature. Four perspectives are briefly reviewed here:

- Shared Situation Awareness
- Advanced Team Decision Making
- Team Sensemaking
- Common Ground

A critical distinction in the literature is the difference between the shared understanding of the process itself and the shared understanding of the state of the situation in the external world. Shared understanding of the process itself has been discussed in the context of the notion of "team mind" or "team schema" which includes the team member's understanding of the team members' individual roles and functions, and the processes to be used (team metacognition). The alternate perspective is the degree to which team members share information, understanding, and expectations about what is occurring in the task environment and how that affects their plans, decisions, and actions. Team mental models, team schema, team member shared schema (Rentsch & Hall, 1994), Advanced Team Decision Making (ATDM) model (Zsambok, Klein, Kyne, & Klinger, 1992b) and team mind (Thordsen & Klein, 1989) are all notions that relate primarily to the former perspective. Shared situation awareness, common ground, and team sensemaking are all concepts relating to the latter perspective. For our current research and development interests in joint emergency response operations, we believe the latter perspective to be more relevant to the representation of a Common Operating Picture. Here, we provide an overview of this perspective on shared understanding.

Shared Situation Awareness

Endsley (1995b) defines situation awareness as, the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future. Unfortunately, no such concise definition for “shared” situation awareness exists. Situation awareness includes the processes of perceiving, comprehending and projecting. For shared situation awareness, the implication is that it is a “thing” that is common to all team members. However, if we take the perspective of process versus product, then the mechanisms for sharing situation awareness become the focus rather than what it is exactly that is shared. Several different related psychological constructs have been connected with the notion of shared situation awareness.

Team mental models, team schema, and shared schema are primarily aimed at team work and the understanding of team metacognitive issues. Shared Situation Awareness (SA) (Endsley & Bolstad, 1994) focuses on the external world, shared SA requirements (which information concerning the current situation and environment do other team members need), artifacts of shared SA (shared SA devices), processes of sharing SA (processes for sharing information), and mechanisms for shared SA (such as shared mental models of other’s roles and functions).

Endsley’s (1995a) definition of SA includes three levels of SA: data, comprehension, and projection. The first Data level implies the degree to which the individual (or team in our case) has the relevant data about the situation. The Comprehension level is a description of how those data are turned into an understanding of the current situation, and the Projection level relates to the ability of the decision maker/s to understand the future trajectories and implications of a situation. It is relatively straightforward to share data and information through the many technological capabilities in network centric operations. However, the critical challenge is how people generate an understanding of the significance of those data and the implications for planning and execution. Therefore, for our purposes, we will be focused primarily on the nature of comprehension and projection (levels two and three) and how they are shared within teams: that is, “shared understanding.”

Advanced Team Decision Making Model

The Advanced Team Decision Making (ATDM) model was developed based on field observations and interviews with expert teams (Zsambok, Klein, Kyne, & Klinger, (1992a). The model emphasizes cognitive functions such as the way teams communicate intent, maintain situation awareness, and provide clarity about roles and functions. Several dimensions of effective teams are identified in the model, some of which relate to the understanding of internal team processes, and some of which related to the team’s understanding of the external situation. The latter are related to our research question of exploring shared understanding. The dimensions related to the current research include: Team Identity, Team Conceptual Level, and Team Self Monitoring.

Team Identity is the extent to which team members conceive of the team as an interdependent entity. This identity influences the way they operate to complete their tasks and missions, how resources are shared, and how information is pushed to and pulled from other team members.

Team Conceptual Level describes the collective power of the knowledge, experience and diversity of the team and how those resources are brought to bear on gathering data, comprehending the meaning of the situation, and identifying future trajectories and implications of the current situation.

Finally, Team Self Monitoring describes the ability of the team to observe and monitor itself. Unlike the other levels, which are states of being, self-monitoring it is a regulatory process that allows teams to effectively exercise the other processes in the model. Self monitoring allows the team to modify the way it is performing when problems arise, and meet deadlines efficiently.

The ATDM model is a model of expert team decision making, which relies heavily on a team's shared understanding of its own processes as well as the external world in which it works. We did not leverage this model directly in our COPE work, but have identified ATDM as a relevant perspective for considering the shared understanding problem.

Team Sensemaking

The notion of sensemaking as a required activity that supplements the process of situation assessment described by Endsley is relatively recent (Klein, Phillips, Battaglia, Wiggins, & Ross, 2002). Sensemaking is the act of creating understanding from a set of disparate data. Sensemaking may include the initial assessment of a situation based on available data and existing knowledge or experience. Sensemaking, however, is most prevalent when an anomaly or surprise is experienced, or where new information or events do not fit the decision maker's current understanding. This forces the decision maker to explain the surprise/anomaly to generate a new understanding of the situation. Put a different way, sensemaking incidents are often signalled by a surprise which initiates the sensemaking activities of trying to fit data to frames (existing knowledge, schema, or stories that supported the initial understanding of the situation). Fitting data to frames and frames to data is the process of sensemaking according to Klein et al. Sensemaking supplements the process of situation assessment, but it is also the process through which SA is achieved. This relates to shared SA (described earlier) and illustrates why the concept of sensemaking is important to the current work.

Sensemaking was initially postulated in the context of individual cognition. However, there are instances where the surprise or breakdown occurs in situations where more than one person is responsible for assessing and understanding the situation. Team sensemaking seems to be related to our current interest in shared understanding, particularly in the context of breakdowns or disconnects in common ground and share understanding that have to be repaired in order to make plans and decisions. In terms of observing and explaining team sensemaking activities, a COPE system needs to recognize the following:

- Aspects of a situation that let the team know that the members' understanding was inaccurate or that opinions differed
- Support for the team to recover their understanding or get back in sync
- Helping the primary decision maker or other members of the team answering questions about the situation ? How does COPE support them in finding the answers?
- Managing the uncertainty associated with information that a team misses or does not pay as much attention to as they should have?
- Support in managing conflicting viewpoints, and how those viewpoints are resolved

Common Ground

The term common ground comes from research in the communications literature (Clark & Brennan, 1991), where the communicator/sender and receiver must share some common understanding or common ground in order to understand the conversation. The notion of common ground has recently been expanded to describe the requirements for collaborative groups and teams to make effective plans and decisions in complex work environments (Klein , Armstrong, Woods, Gokulachandra, & Klein, 2000). Common ground refers to the basic shared assumptions and responsibilities (or basic pact) that a team shares and from which all future activity can be calibrated. A critical aspect of collaborative cognitive activity is that this basic pact acts as a baseline against which anomalous situations and behaviour can be judged and breakdowns in common ground identified and repaired. For example, in a collocated/open workspace, team members can:

- Hear and see what others are doing and looking at with little effort, making it easier to recognize when a team member is behaving unexpectedly and to obtain an explanation for his/her behaviour. (A question related to the current research is: How do distributed team members obtain explanations for behaviour that may be unexpected?)
- Speak directly to each other to repair breakdowns in common ground
- Be simultaneously heard and understood without delays between the initiation of a communication and its reception
- Share a common information space and shared visual **(**and probably auditory) access to data and activity
- Track the status of progress on tasks assigned and mesh their activities with others without explicit communication
- Redirect each other's attention easily to a disruption to the plan in progress

The concept of common ground was taken as a primary goal for the COPE technologies to support. A focus on breakdowns or disconnects in common ground/shared understanding could be taken as a starting point for evaluation of the effectiveness of COPE technologies in repairing these common ground breakdowns.

Designing for Shared Situation Awareness

Endsley et al. (2003) describe 50 principles of designing for situation awareness (SA). Four or five of those principles are intended to directly address the display of information to support shared SA. The COPE technology solutions should take the following priniciples into account in support of shared understanding of the operational situation and required coordination of actions:
Principle 45: Build a common picture to support team operations
Principle 46: Avoid display overload in shared displays
Principle 47: Provide flexibility to support shared SA across functions
Principle 48: Support transmission of different comprehensions and projections across teams.

2.2 Previous COPE definition of COP

In the COPE project, Common Operational Picture (COP) was defined as follows: "COP is the description in time of the emergency situation that supports the emergency responders within and between different agencies to act appropriately."

We have taken the primary functions of the COP as: supporting the development and maintenance of common ground and the support of coordinated action across actors.

We consider further that COP is a pool of information

- that is registered and stored in a database
- concerns past, present and expected future events
- that is available for presentation in a user interface suitable for emergency responder work

- the form of presentation of which is consistent and unambiguous, but not necessarily similar to all stakeholders
- the content of which is structured around operational processes of the emergency responder
- that needs to be interpreted and acted upon by the emergency responders
- that is meaningful in the context of emergency responder work.

A concrete definition of COP can only be provided in the context of a user/user activity, the information systems/sensors at his/her disposal, and a specific operational scenario. We are moving towards these definitions with our WP2, 3 & 4 work. We can say something about what we believe a COP is intended to support (with respect to multi-agency operations). Technologists input is extremely important here. There is definitely an interoperability issue here with respect to the technology interfaces and visualization/representation formats (e.g. symbology). We can start working on these to an extent already, with WP5 partners.

3 Interview study: Incident Commander (IC) decision making in present operations

COPE project combines technical expertise with users' needs - parties working in the field for emergency response purposes. Interviewing field workers about their experiences related to some specific incident confirms that, given the time available, all relevant matters in that specific real-life situation are covered in the course of the interview. Specifically, such interviews shed light on working context and the way the tools currently available are used in these situations. When specifically ideas of the present and future tools are asked about, fruitful information is gained regarding the needs and practical limitations of the technology that is or can be used for rescue purposes.

Our project is focused on Incident Commander, so Incident Commanders were to be interviewed. Decision making is one turning point in the sequence of the rescue process where the operational picture is important and can be assumed to become more apparent from two perspectives. Firstly, Incident Commander makes the decisions according to his operational picture. Secondly, by acting in the world this conception is mediated also to other parties – fire fighters and other agencies possibly affected, such as other public officials (police and medical care).

3.1 Interview method

Our interview method was based on the Critical Decision Method (Klein, Calderwood, & Macgregor, 1989) to elicit lived experiences from fire fighters, and to ground discussion in real events (versus hypothetical scenarios that will often elicit only opinion and generalizations).

The interviewer attempted to elicit lived-incidents from the interviewees. A 'lived-incident' means an incident in which the interviewee was personally involved and not "well there was this one time my friend went to this big fire and…". The incident had to come from the interviewee's personal experience.

The interview methodology can be described in terms of 'sweeps' or multiple accounts or iterations of the same incident, focusing on different levels and types of information each time (Crandall, Klein & Hoffman, 2007). The method was described thoroughly in the document D2.1, so here only an outline of the method is presented.

The CDM was adapted with a final sweep through the incident where the interviewer presents the interviewee with the opportunity to envision the use of various technologies in the context of the previously experienced event (or in future interviews, explore the role of the evolving CONOPs in the context of a past incident).

3.2 Interviewees and the accomplishment of the interviews

We interviewed people who have been in a leading role, preferably as Incident Commander, in a difficult rescue situation, preferably with multiple agencies involved. The interviewees were acquired by asking one fire fighter in a course for superiors in ESC to ask his colleagues to participate in this study. COPE project and interview context was explained to him by talk and later by email and he passed this information to interview candidates. All candidates with whom an interview time could be agreed on were interviewed. We had two interviewers and in part of the interviews, a support person (colleague of another interviewer) was also present, meaning that in some cases, interviewer was alone with the interviewee and in others, there was an additional person present as well.

Each interview can be divided into four sections or “sweeps”. Firstly, the experience to be told was chosen. Usually, the demanding experience in which the interviewee has been in a commanding role was so evident that only that one was talked about.

Secondly, events of the incident were identified and its decision points were put on a timeline. In some cases, the timeline was drawn and in others, it was only expressed by speech.

Thirdly, each decision point was deepened. At this point, interviewer was more active, asking questions related to that specific situation for identifying its intrinsic cognitive demands.

Fourthly, the interviewee was asked about the role of the technology and how new technology could have helped in the incident if it were invented and available.

4 Results of the interview study

4.1 The elicited incidents

Interview was performed to five first responders that were on supervisory role at the incident, as Incident Commander or Sector Commander. The interviewees and incident types were as follows:

- Incident Commander, sheltered home burning on 1999, a multi-unit response with multiple agencies
- Incident Commander, strangled victim in a stair hall in a block of flats on 2002 or 2003, with multiple agencies
- Incident Commander, forest fire on 2006, duration 3 days, a multi-unit response with cooperation with other organisations (forest experts etc)
- Sector Commander who first acted as the leading authority at the incident site, minor explosion due to an unknown reason at the centre of the capital on autumn 2008 (half a year before the interview), multiple agencies
- Sector Commander, rooms burning in a block of flats, on winter 2009 (one week before the interview), a multi-unit response with multiple agencies

4.2 General operational instructions

The **incident seems to be mentally structured by common, obvious changes** in the situation. Deciding to perform a task is expressed as a natural consequence of the situation, not as something that requires specific decision making. Hence, as interviewees were asked to divide the incident in sections according to decision points, this was not done but instead, the incident was divided according to major, somewhat official changes. Hence, incident-related personal decision points were not usually labelling the perceived sequences as expressed by the interviewees. The first phase was usually named as receiving the alarm, the second one as arriving to the scene, the next ones when some other party arrives, when the responsibility is transferred from one party to another etc, until the incident-related tasks are finished and the crew returns to the fire station.

So, the flow of events seems to be perceived as divided into sections roughly according to official changes in the situation, somewhat similar in nature with the general operational instructions. This may reflect fire fighters' training – general operational instructions are vital to internalize as they are means of making quick and important decisions. These instructions are the ones that are also easily expressed by words and they reflect such changes that are easily traceable. Instead, incident-related decision points such as what to do when fire suddenly increases in power or the like were not mentioned at all as structuring the incident. Possibly, they represent the kind of situations that require such speed of decision that they are not experienced as decision points at all. Instead, they appear to the fire fighter as a "natural consequence" of the situation. This is probably not the case but the perceived smoothness of event sequences may reflect the overlearning of tactics that saves one's or other people's lives – the result of efficient teaching for a valuable reason. Additionally, the experienced "naturalness" may be the flip side of the correctness of the decision. When thinking back of a stressful situation, when things have gone right, the decisions made appear as natural, with no other options.

General operational instructions appear to be extremely important. Having adopted them, the **overall organisation and the sequence of events** is known for everyone. Hence, it was self evident for all interviewees what party is **responsible** for the lead of the incident and if responsibility is transferred, when the it is transferred to another party. Apparently, the nature of the incident is the criterion for responsibility – e.g., if physical violence is in question, police will be in charge, if the violent person might be at site, a dog will be the first to visit the scene etc.

Also the extensions of responsibilities are predefined. IC is the general leader who delegates tasks to Sector Commanders. They, in turn, pass the task to their team with more detailed instructions of what to do. The incident-related information from the field, sent by Sector Commanders, are taken into account when Incident Commander decides what should be done next.

In an unexpected situation that requires instant decision making and when being first in the incident site, the authority in question is supposed to act immediately, without asking anyone. Most incidents types are met frequently so that working takes place according to normal routines, even if the nature of the work simultaneously requires constant vigilance.

Also **emergency rescue-related working roles,** defined in the general operational instructions, support security. Fire fighters work in pairs, completing each other's work and providing safety to one another. Furthermore, nowadays also the Sector Commander goes into the burning building with his crew, holding the thermographic camera to secure and assist the work of his fire fighters (Incident Commander never goes to the fire but stays outside; he may only have a closer look afterwards for reporting purposes).

When there are fire fighters in the house with breathing apparatus, there is always one man outside taking care that nobody is inside too long so that there would be lack of oxygen, contacting the fire fighter when there is time to get out from the building (100 bar pressure). Additionally, there is another pair waiting outside if possible, having their own air tubing. This pair takes this tubing to the pair inside if the inside fire fighters get short of air.

Roles are changed according to incident demands. For instance, when the incident does not appear to be severe and only one fire engine is dispatched, the person in charge in the field, i.e. Incident Commander, can be of lower rank. However, if the situation proves to be more demanding and more fire engines are needed, a person of higher rank will be called to manage the situation as Incident Commander and the previous commander is transferred to the role of a Sector Commander.

4.3 The role of tools

Here, only such tools are mentioned that aid in decision making, delivering relevant information or are means of communication or the like. In the following, only the opinion of the interviewees is expressed.

4.3.1 General information exchange

General information exchange by voice or text: TETRA radio network used between authorities

The most central tool for communication between all public authorities dealing with an incident is radio network, based on TETRA standard, which can be used for talking and sending specific types of messages, used by mobile phones. Radio talk uses normally a base transceiver station. If the connection is poor such as when in a cellar low below the ground or when there are several thick walls and floors made of concrete, the connection to the base is usually lost. Then the radios can be connected to each other so that only a few radios talk with each other. Sometimes there are troubles in hearing even then due to the walls that are too thick. When descending, fire fighter can make trial calls to check the existence of connection between the radios.

Emergency Response Centre dispatches authorities. The centre makes a phone call to fire station and/or other authorities, according to the incident type, and sends a text message to the vehicle(s) that are dispatched (the authorities and number of vehicles to be dispatched are predefined in software application used by the Emergency Response Centre). The text message, informing about the incident and its address, is received by the vehicle's cellular that is connected to TETRA, authorities' network. On the way to the incident the IC can ask for additional information from the Emergency Response Centre by phone.

The role of the Emergency Response Centre is vital in the beginning of the incident handling. In addition to alarming, Emergency Response Centre receives the status of authorities so that Emergency Response Centre always knows the situation of parties involved. By pushing one of four buttons, the authority can in form that the vehicle is (i) on its way to the incident site, (ii) at the site, (iii) on the way to the station or (iv) at the fire station. This way the Emergency Response Centre knows what is the situation related to parties involved to the incident and can convey that information to IC who is e.g. waiting for more authorities to arrive to the incident site. Emergency Response Centre also dispatches more vehicles if needed and informs vehicles approaching the incident site about the incident. This information is based on the emergency phone call made by a citizen, status information sent by dispatched vehicles and by possibly made requests for more authorities to the site.

A specific TETRA bandwidth is chosen for communication related to a specific incident, used by parties that work at the incident site. The bandwidth is always the one that is dedicated to the IC responsible for that specific incident. The identity of IC is told by Emergency Response Centre when dispatching the units to the site. As all important talk is mediated by TETRA, all stakeholders (IC, sector commanders, other authorities at site, Emergency Response Centre) are able to hear and know what is going on without specific measures, just by choosing the correct bandwidth and by listening the talk. Radio talk is also used between the crew that is performing rescue services and its commander. IC can use TETRA to call the Emergency Response Centre for more help or to talk with colleagues coming to the same site or to talk with sector commanders or other authorities that work for the same incident.

Information exchange seems to be quite effective with the exception of talking in the burning house. There the noise level is so high that it is occasionally hard to hear what is said. This is an important deficiency as paradoxically, this is the situation where safety is at risk the most. Many cellulars are functional in normal conditions but melt in fire, even if the cellular can be connected to the helmet and the voice is heard inside of it. TETRA mobile is quite heat resistant but it can not be connected inside the helmet and there may be difficulties in maintaining contact.

Receiving and delivering information as well as keeping diary: Computer connection
Personnel in fire station's control room may send information to the fire engine by sending data to fire engine's computers such as graphs about the local fire hose system. Incident Commander uses computer for e.g. keeping diary of the incident and with a printer attached to the computer, a map of the incident site can be print to be delivered to Sector Commanders.

Rapid information exchange with other organisations and when TETRA is not functional: Mobile phone (GSM)
GSM can be used in TETRA's shadow area and for communication between parties that do not use TETRA (private organisations and the like).

Information exchange between the fire fighters in the burning building: Radio talk and hose
Fire fighters that work in pairs can talk with each other and when talking is not possible, they have contact via the fire hose. Hence, a hose is not only a means for transporting water into the burning building but also a security-providing tool keeping the working pair safely together as men always

hold the hose when in the burning building. The hose helps in keeping the fire fighters together and it also leads their way out. When there is no visibility at all, the fighters grab the hose closely to each other. That way the other party knows what is the situation of the other one.

4.3.2 Localisation of fire

Street address of the incident site: GPS
Command vehicle may have GPS that helps in orienting in the streets and leads to the correct location, showing current position of the vehicle and the one of the target. If without GPS, maps and knowledge of local area (if there is any) are used. Furthermore, GPS sometimes shows wrong direction so that knowledge of local area is needed anyway.

Detailed geographical information related to forest: Can be asked by e-mail
When extinguishing forest fire, it should be known what the forest type is, what is the landscape like, what is the nearest road like, what is the nearest water source like etc. This information can be asked by email from authorities.

Location of burning forest: Forest fire appliance
A small airplane is flying regularly around a forest during a state of alarm for forest fire, belonging to rescue department. Any other small airplane can be used also at other times but then it takes a longer time to find a pilot. Furthermore, as it is not part of Emergency Response activities that can be used directly but to general resources, its use must be asked from Emergency Response Centre. Generally, when the weather is suitable for forest fire, it also is suitable for flying.

Location of fire according to the alarm sent by the fire alarm system: Map and localisation chart
When fire fighters are dispatched due to an alarm sent by a fire alarm system, Emergency Response Centre reports the fire station the address of the fire alarm system. The dispatching alarm is sent from that address and when arriving there, the system is still sending an audio signal. This system is connected to several fire alarm systems and the initial cause of the alarming signal can be any of them; the system shows by a number combination (such as 02.121 or the like) what is the initially alarming system. There is a localisation chart that tells what system group that specific system (02.121) belongs to and by checking the correct group, the address of the initial system can be found. There is also a map that shows where that specific system is located. The map can be taken along to find the initial fire alarm system for checking if it is a correct alarm – most of those alarms are false ones.

Finding the heat source: Thermographic camera
Thermographic camera is used for finding the heat source. As the camera scales measuring unit according to the surrounding heat level, it can also show the location of the human being by showing also small differences between heat levels. The cameras are nowadays smaller so that they are easier to carry along. There is a recommendation in Finland that every fire station should have one camera.

Apparently, thermographic camera is one of the central tools used in the emergency services. If that could be made light enough to be attached to each fire fighting gear, that would help a lot of the fire fighters' work. There as been several designs where the camera has been part of the fire fighter's helmet but so far, they have been too big and heavy to be usable at the work.

4.3.3 Coping with severe conditions

Working in difficult breathing conditions: Breathing apparatus with a localiser
When working in smoke, breathing apparatus is needed. Everyone is responsible for being aware of one's air pressure situation. When there is air left only for reserve purposes (50 bar pressure), an alarming whistle in the apparatus tells that one must go immediately out. According to the interviewee, breathing apparatus alarms a bit too late about the approaching lack of air. There is also one man who is responsible for knowing how long each fire fighter has been inside the building so that he knows when to call them back to get more air and at least after 15 minutes working.

Telling colleagues about the general condition of a fire fighter: Movement detector
Movement detector attached to the fire fighter is activated when a dangerous task starts. It automatically starts to send a warning signal when the fire fighter has not moved for 20 sec but stops if the fire fighter moves. If there is no movement followed by the warning soon enough, the warning can be stopped by pressing several buttons. In practice, they are generally not used. They are experienced futile or maybe even adding work load unnecessarily as fire fighter may stand still long times without being in trouble; then, IC should dedicate time unnecessarily in checking the reason for each alarm.

4.3.4 Keeping track of the situation

Taking notes at the incident site: Pen and notebook
Pen and notebook are sometimes used at the incident site, especially when walking at the site, even if the actual notes are edited by a computer in the Command Vehicle.

Maintaining situation awareness: White board, diary written on paper or the like
Incident Commander often makes notes about the most important commands and the like to keep track of what has been done and for making appropriate decisions for the future. There is no official tool for that – one of the most general ones might be pen and paper, and white board in the Command Vehicle.

4.3.5 Acquiring incident-related general information

Being informed about buildings: Information card
There is information available for rescue services about all public buildings at least. These information cards are not necessarily in the form of a card but can be in any format. The card contains information relevant to rescue activities such as floor plan, the existence of dangerous substances, matters requiring specific attention etc. Execution of the document is under the responsibility of the owner of the building and it is obligatory in public buildings.

Looking for specific information: Handbooks, guides and the like
Incident Commander has handbooks and other information sources in paper or in a digital format in the Command Vehicle. His or his driver's task is to find crucial information related to the incident in question, such as the level of toxicity and the corresponding need for protective measures related to some substance released at the incident site.

4.3.6 Expressed wishes for new tools

A wish for a tool that would identify chemicals and gas when they are related to fire was expressed. That would make fire extinction quicker, fire fighters' working safer and would make surrounding protection to be founded on sound basis. Apparently, at least in Helsinki a gas detector is available for specialised chemical divers (in Helsinki area, there is one) but it recognises gas in one spot according to the library that is activated. If a wrong, for instance a military library is on, the detector may shout “chemical war” gas where it is actually something that is breathable (this happened in an incident with a minor explosion).

In some instances it would be highly beneficial to have a structural drawing of a building so that ways out and possible locations for people could be immediately identified.

Instead of being obliged to ask somebody to send a satellite image and information related to the quality of forest roads, water supplies and the like for forest fire extinguishing purposes, it would be practical to have a map with the needed details to be readily available for rescue purposes.

It would be very helpful if all relevant information related to a specific type of an incident (forest fire, structural fire) were easily available in one location: map (geographical of the area, floor plan of a building) should be readily available and contact information to all stakeholders should be listed. Now, incorrect estimates are done due to lack of information and time is wasted for finding the information needed.

4.4 General considerations regarding fire fighters’ tools

The work of fire fighters is safety critical both from the point of view of the possible civilians in the fire and the one of the fire fighter himself. The fire fighting gear with the general apparatus is heavy to wear and hard to move with. Much of work strain results from the fire fighting gear because heat, produced by the moving human body, can not evaporate or exit otherwise from the inside of the gear.

When working in burning facilities, face shield gets sooty, making seeing around more difficult. Noise around due to fire makes talking difficult and the stressing situation makes the production of longer coherent sentences difficult. Hence, secondary tasks related to manipulating a new tool or modifications to some tool used currently should burden as little as possible the fire fighter. Furthermore, not very many secondary tasks should be added to fire fighters’ work as they weaken safety by making the fire fighters shift their attention from the dangerous surroundings into something else.

If seeing is needed in the user interface of the tool, the interface should be extremely simple by structure (intuitive) and as clear as possible to be perceivable in difficult viewing conditions.

Communication should not rely much on talking as talking and/or hearing may be impossible in the moment it is needed.

User interface that requires manipulation should be very simple, requiring preferably only pressing a button or the like. Noticing any outside signal is hard when working in burning facilities with the fire fighting gear and breathing apparatus on.

When the tool is to be used in challenging circumstances, it should be easy to use and reliable so that it is functional in all situations if possible. This means that it gets connection to other devices when needed and the information should be transferred from that device to the other one without difficulties. If the device is to be used in the field, it should be water resistant, heat resistant, cold resistant, the charge of the battery should be long lasting, user interface should make possible seeing in various viewing conditions and not sensitive to dirt and the device should not be very heavy.

The more you get technical devices the more you need time to learn to use it. This diminishes the value of new devices. Hence, one device should be as multifunctional as possible. For instance, when a forest fire is in question, one “box” could deliver as much information as possible, related to forest in that area: authorities involved, telephone numbers where to call, dangers specific to that kind of incident, geographical map that is up to date and the like.

Fire fighters are not prone to try new devices easily. The considerations regarding the tools to be used by fire fighters and between fire fighter and Incident Commander communication reflect the hard circumstances they work in. Being heavily stressed both physically and mentally, no new requirements related to manipulating new tools are wished for. Obviously this is partly justified as such as too much mental and/or physical load may result in the loss of somebody’s life. Partly this also reflects the importance of routines that are formed during training and in working life. This obstacle can be alleviated by training. When the use of a device is taught during the initial training, it becomes part of the work and is more easily adopted. If some new device is introduced at working life, the device should be highly important and very easy to use, as perceived by the fire fighters, to be adopted as part of general working routines.

5 Kuopio design study: Approach and methods

5.1 Introduction and aims

The study described in this chapter was labelled a design study. By this characterisation we aimed to indicate the innovative, as contrast to evaluative, character of the study. The aim of the study was to create a real like usage situation in which new knowledge of the needs and possibilities of new technologies could be experimented. Experimenting with complex professional tools assumes professional users. We also made an extra effort to create as realistic a context as possible. While innovative in character we still wanted that the study provides experience that may be structured and reflected upon. Hence, conceptual and methodical means were needed in the design of the study, in data collection and analysis of the results.

The design study described in the following was accomplished with the aim to estimate the added value that Wireless Sensor Network (WSN) technologies to emergency response in fighting hazardous substances. In searching the possible added value we decided to observe how the construction of Common Operational Picture in the present fire fighting practice in a particular emergency situation would take place, and to compare this to the situation with some new technology. WSN is conceived as one element of the COPE-technology for COP.

The COPE partners involved in this design study are VTT tech and VTT HF, ESC and UTI. The study was accomplished at the Emergency Services College in Kuopio. The college made its test field facilities available for the COPE project. The design study was embedded in a comprehensive student exercise that was designed in collaboration with ESC instructors and experts. The exercise was also led by the ESC instructors. The COPE partners were responsible to extend the exercise so that it could meet the aims of research and design. The technical part of the study has been reported in detail separately in the D5.1.4 by WP5. The context of the design study supported the development of the solutions.

5.2 Emergency response activity studied

5.2.1 The accident situation

The emergency response activity was studied in a realistic exercise situation with 23 Emergency Services College students participating. The exercise was one of the final practical exercises before the students of the warrant officer course were supposed to receive their diplomas and be ready to take a job in the field. The exercise focused on fighting accidents with hazardous material. The emergency response activity was viewed from the perspective of the Incident Commander.

The situation involved a release of hazardous material i.e. ammonium NH_3 in the environment. The leaking ammonium evaporates rather rapidly in the temperature around 10 degrees C and forms a cloud that threatens the inhabitants living in a nearby residential area.

The accident was caused by a collision that took place in the morning hours between a truck, driven by the driver alone, transporting about 20 000 kg ammonium, and a passenger car, also occupied only with a driver. The situation is depicted in Figure 9 and a photo of the exercise is in Figure 10.

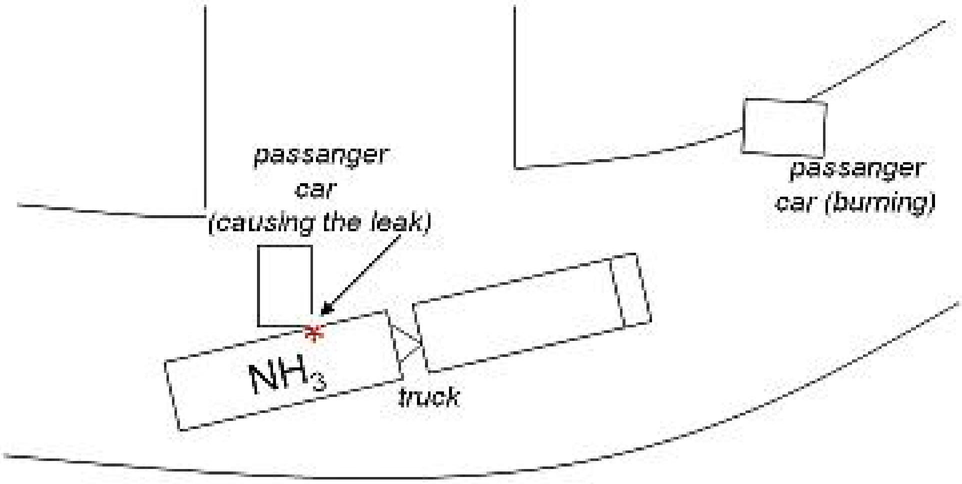

Figure 1. The collision between an ammonium truck and two passenger cars.

The truck was driving along a main road, while the passenger car was approaching from a side road behind a stop sign. The driver of the passenger car did not observe the truck and attempted to turn left to the main road in front of the truck. The truck driver did not have time to break or yield as the car proceeded unexpectedly onto the main road. A further passenger car that approached the junction along the main road from an opposite direction to the truck hit the truck that had blocked the road completely. This second passenger car caught fire, and the driver, who was alone in the car, perished in the flames. In the collision the ammonium tank of the truck got a leak of considerable size (kilograms/min). The first passenger car driver got severe mechanical injuries and perished immediately. Also the truck driver was injured, but remained conscious. In this state he still was able to make an emergency call but could not give further details of the situation.

Figure 2. The simulated collision. In the picture the evaporated gas may be seen to escape from the leak. A very small ammonium concentration was used

The Emergency Response Centre identified the need for a "company response" including three emergency response units with manning of 5+1 and the Incident Commander. The Emergency Response Centre did not receive exact information of the hazardous substance involved. The first fire engine reached the accident site in 10 minutes.

5.2.2 Analysis of the emergency response tasks in the situation

A two-phase task analysis was accomplished to describe the expected emergency response activity in a situation described above. The phases were creation of the *Functional Situation Model*, and defining the *decision making demands*.

In the task analysis the current Finnish ER practices was the reference. We used written material and guides (Lautkaski et al 2006; Mäkelä 2007; Neuvonen et al 2007) concerning emergency response in fighting hazardous substances as the background. We also consulted experts and instructors of the Emergency Services College. Mr. Kyösti Survo informed about hazardous materials and Mr. Kari Junttila about information systems. Furthermore, Mr. Survo also led a workshop with trainers involved in the exercise, letting us know more about the exercise arrangements. We also observed the analysis of Incident Commanders' task described in COPE D3.2.

5.2.2.1 Functional Situation Model of the hazardous substance accident

The functional situation model describes an activity in a *situation*. The model is depicted in Table 1. The model makes use of a *temporal* dimension of activity by describing the main phases of accomplishing an emergency response that, in the studied situation, is launched by a collision between three vehicles. The collision caused three major problems: injured people, fire, and an ammonium leakage. The last problem is the most demanding one in this situation. The phases of the task are: alarm, reconnaissance, stabilization, restriction of danger and finishing ER.

In modelling the response activities also an *intentional* dimension is utilised. By making explicit the purposes and overall goals of emergency response, i.e. protection of life, protection of environment and protection of property, a backbone for the activity is constituted with reference to which situation specific *functions* that are required to fulfil the purposes are defined. These functions, sixteen altogether, are inferred on the basis of existing guides concerning practices in fighting hazardous substances. Finally, the model also makes explicit what information is critical to identify the state of the functions, and via which medium the information is conveyed, and to what actions the information give rise to.

The Functional Situation Model provided a reference for further work of the design study as it

- served as a guide to making *observations* of the real activity that took place in the exercise.
- served as a guide in the *analysis* of the real activity. The model was used as a description of possible actions and decisions, and reasons for acting in the situation. The description was compared with real actions and decisions, and with the reasons given to them in the exercise.
- provided basis to *formulate performance-based evaluation criteria* for the assessment of the particular COPE technology (to be elaborated later).

In the construction of he Functional Situation Model we took advantage of the VTT Human Factors group's earlier work in corresponding domains (Norros 2004; Savioja et al. 2008; Nuutinen and Norros 2009).

PHASES, MAIN PURPOSES AND FUNCTIONS	Actions and actor	Information and Medium
INITIAL SITUATION Collision between the truck driving on main road, loaded with NH3, and a turning passenger car behind caution sign. After the collision, a second passenger car hits the truck. Ammonium leakage from the truck Casualties in all three cars Fire in the second person		Background: Transported usually in 20 000 kg, 80% filling, no cells; If leakage, in liquid form; evaporates well in 10 degrees C; NH3 lighter than air, cloud spreads with wind; 1200m in 10 min. indications of leak: smell3 ppm, smarting of eyes 50ppm, danger to life 5000 ppm; within 300 m possible concentration 100 000 ppm
ALARM Call to 112 by the truck driver. On the way to site	*Call centre*: Sends IC (+ command truck) + 3 fire units (5+1), chemical divers; 1 ambulance unit *IC:* get information, prepare for identification of chemical, *IC: Tasking* Orders to units concerneing reconnaisance, advice *police*, prepare for use of protective equipment	No information of chemical / VIRVE net speech areas:1: CC-IC; 2: IC-unit leader; 3,4,5 within each unit wind direction, speed, temperature, humidity; consult YK, VAK booklets, guides; VIRVE IP
RECONNAISSANCE Search for information Accident severity estimation Decision for tactics	*IC*:Approach above wind sufficently protected. … observe casualties, inquire from driver if possible since isured , search tags and documents from the truck, e.g bill of freight, *IC:* Chemicals, danger for explosion, inflammability, spread, development, rapid measures, resources: personnel,equipment, *IC:* Consider possible escalation, deficiencies of information, draw on own observations. First decisions often decisive. .. … Offend the biggest threat, create focus. Tactical optios: 1) Take effective measures to prevent or restrict accident consequences 2) Use all resources to protect people. Update interpretation of the situation. Anticipate and take a strong leadership.	Wind direction and speed, "orange tag",type of danger number… or Hazchem number,YK-number (specifies the substance), quantity of chemical, car register number, owner; leak size and place , inhabitants, environment, nature Possible use of measurements. TOKEVA M1, M4a, T2g, use *experts* in predicting future course of the event COP: Availbale artefacts for illustrating COP: General maps, situation maps, plans; writing boards, data projector, Map-info programme, resource bulletin board, infrastructue maps, whether map, ..layer drawing
STABILIZATION Protection of life Protection of environment Protection of property First Aid and trans-portation Fire fighter presonal protection Estabilishing rinsing area Extinguishing Car fire Estabilishing danger zone Prevent chemical fire Stopping the leak Prevent from spreading	*Ambulance*: 3 c asualties, triage: 1 patient to treat and deliver to hospital, both car drivers lost; *FF:* Breathing mask, overalls, protective gloves, spill, chemical or fire overalls *IC*: Define the shape and size of protection zone (immediate isolation 300m and 40 degrees 1000-1500 m); consider sheltering inside buildings or evacuation *IC*: Command 2 fire fighters+1pump to extinguish the car fire; *IC*: Prevent higher concentrations, inflammation, restrict damages; consider further risks and different extinguishers *FF:* Fill the hole, turn the tank, cover the tank; *IC:* Collect chemical, pumping, neutralizing, soaking, diluting,	Two drivers found dead. Concentration of dangerous substance Counting with computer programmes; also possible to meausure but takes time; Drawings TOKEVA M7b TOKEVA M9
RESTRICTION OF DANGER Difuse the released ammonium Inform relevant authorities	*IC*: Difusing is not simple; if possible, use *experts* IC: Inform relevant *authorities* of damages	
FINISHING ER End emergecy response Remove restrictions Wash contaminated materials	*IC*: Negotiate with other *agencies/ authorities* about withdrawal *IC*: Remove restirctions concerning activity and mobility *IC*: Contaminated equipment and clothing must be cleaned at site, rinsing area.	

Table 1. The Functional Situation Model of fighting ammonium leakage in a severe collision between a tcuck and two passenger cars.

5.2.2.2 Decision making demands of the Incident Commander

In the second phase of the task analysis of the emergency response activity in the tested situation we identified critical decision making demands of the Incident Commander. The demands portray the generic incident commander decision making demands described in the Finnish incident commander guidelines (Neuvonen 2007).

- **Creation and maintenance of awareness of the situation**
  Most important features of the situation to comprehend are
  - are there casualties
  - what is the leaking hazardous substance
  - what is the size of the leak
  - what is the direction and speed of wind, and the temperature and humidity of air
  - what is the actual concentration and spatial spreading of the substance
  - are people threatened by the chemical cloud

- **Organising response activity in three sectors**
  - identify the primary focus of activity and divide resources
  - initiate care of injured people
  -.initiate fire fighting of the burning vehicle
  - initiate chemical fighting

- **Definition of the immediate danger zone**
  - what is the needed level of protection of the first responders
  - what is the working area where it is possible to work without breathing masks

- **Planning of the protection zone and the protection of the population**
  - using the available information e.g. the diffusion model (ESCAPE) define the protection zone
  - coping with uncertainties due wind, and the specific features of the terrain
  - decision for ways of protecting population for chemical

- **Monitoring on-going response activities**

These decision-making demands are in coherence with the more generic descriptions of D3.2 but they are focused on the specific emergency response task in question. Thanks to being context dependent it is also possible to infer what particular aims and which information and other resources the decisions might involve. In the analysis of the Incident Commanders activity these decision making demands are considered as part of the process of constructing COP in the situation.

5.3 Description of the tested technology

The technology developers of WP5 (WP5.5 VTT and WP5.4 UTI) have provided ICT-techniques, especially wireless sensor network (WSN) technologies for the design study in which new possibilities to support emergency operations are studied. In this document used ICT is introduced and the results of the experiment are presented. In this experiment, WSN was used to measure concentrations of hazardous material in the ammonia truck accident (hazardousness of ammonia cloud).

5.3.1 Sensors, weather station, receiver and TETRA network

The sensor network consists of seven sensor nodes including one wireless weather sensor and six field sensor nodes. Even though the sensor network includes several sensor units to measure the ammonia concentration, it would have been really dangerous to actually use realistic amount of hazardous material in an experiment. Therefore, only mild concentration was used. The first unit nearest to the leak measured the ammonia level while the rest five were simulated. However, the receiver was set to simulation mode so that in the experiment, only simulated values of ammonia were used. The simulated values were based on estimated concentrations in the described ammonia leakage accident. The simulated concentrations were also based on the real locations of the sensors and weather conditions. This means that the WSN is used to measure also the GPS locations of the nodes and the local weather information. However, the system can be used in real situations by unchecking the simulation option. Also more sensors can be attached to the system. The technologies used in the experiment are illustrated in the Figure 2 below.

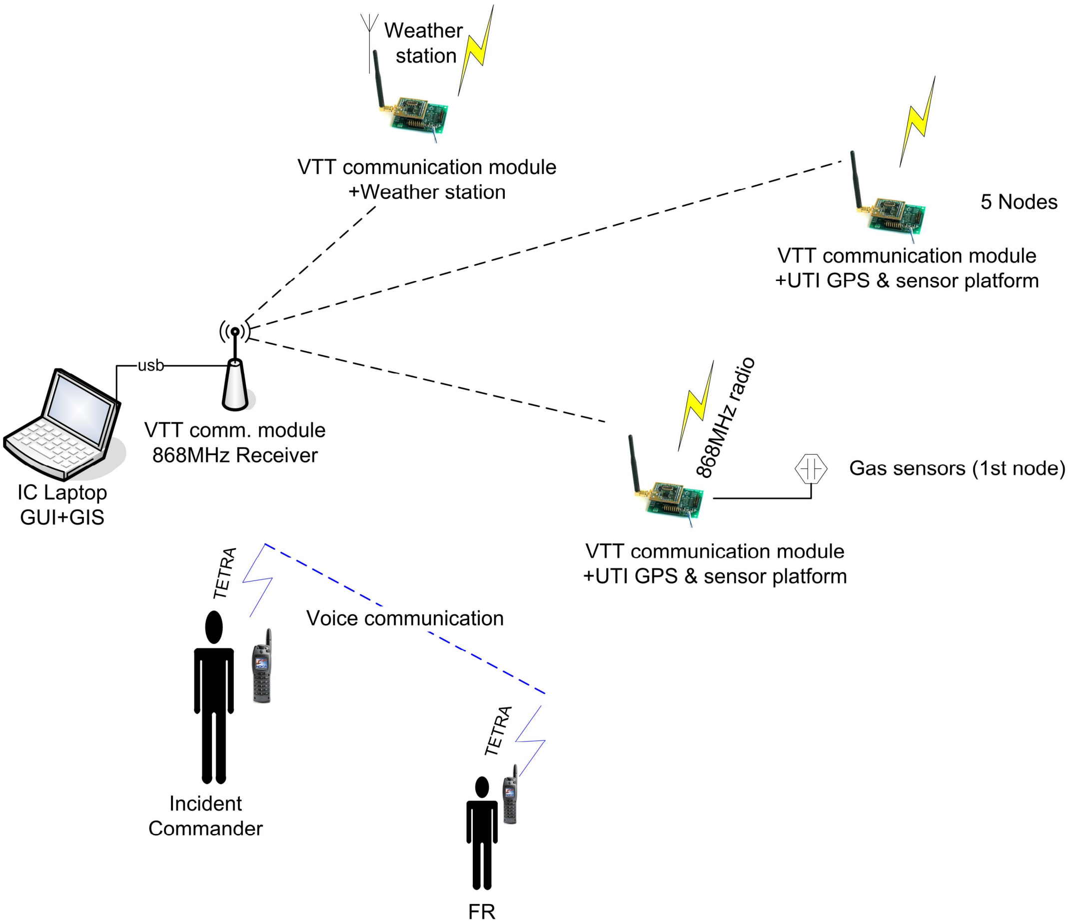

Figure 3. Technologies in the first experiment

The WSN central unit receiver collects sensor location data, weather data and concentration to a laptop PC located in the Command Vehicle. The data is represented on a map to visualise the spreading of the hazardous cloud. The incident commander exploits this map view in the operation. TETRA network is used for voice communication at the incident scene.

The components/units used in the first experiment are listed below:

Ammonia sensor node (1 unit)
Communication Platform
Sensor Platform, incl. GPS (UTI)
Gas detector instrument (Dräger X-am 5000)

Sensor units (5 units)
Communication platform
Sensor Platform, incl. GPS (UTI)
Simulated gas concentration

Wireless weather station (1 unit)
Communication platform (VTT)
Weather sensor (Wind speed, direction, temperature, humidity, air pressure)

Receiver Unit
PC-laptop
Communication platform (VTT)
GUI (incl. map)

TETRA-network (used also normally in emergency response in Finland)
TETRA-radios for voice communication



Figure 4. Pictures from left to right: Sensor unit, weather station and receiver unit PC.

The Communication platform is used for the WSN data transmission. The platform consists of embedded low power sensor network processor, radio modules and general purpose I/O interfaces. The module can be equipped with short range NanoNet radio or with narrow band medium range 868 MHz radio module. In this experiment Radiocrafts RC1280HP 868 MHz radio is used because of low bandwidth and long range requirements. The UTI Sensor Platform is used for sensor data and GPS-data acquisition. The Senor Platform is connected to the communication platform using RS232 interface. Also the Dräger X-am 5000 gas detector is connected with RS232 to the Sensor Platform.

The WSN radios operate in the unlicensed frequency band and the network does not require any existing infrastructure to be used. This is why the ICT used can be utilized anywhere this kinds of incidents occur.

5.3.2 Test Software User Interfaces

The test software includes a graphical user interface with diagnostic windows and control windows. The user interface is presented in figures 3 and 4 below. The software automatically configures the proper communication ports and initializations required to run the software by starting the software. The diagnostic and control panels are for test purposes. User can see the number of transmitted and received radio packets, GPS-data (time, longitude, latitude, speed, course), peripheral flags of the sensor platform, sensor parameters, battery level of communication platform and the simulated/real gas levels. The simulated values can be replaced by adding real sensors and by uncheck of the "simulate" check box. The weather information is also displayed in the diagnostic window. The main window to be displayed to the user is the map window shown in figure 4.

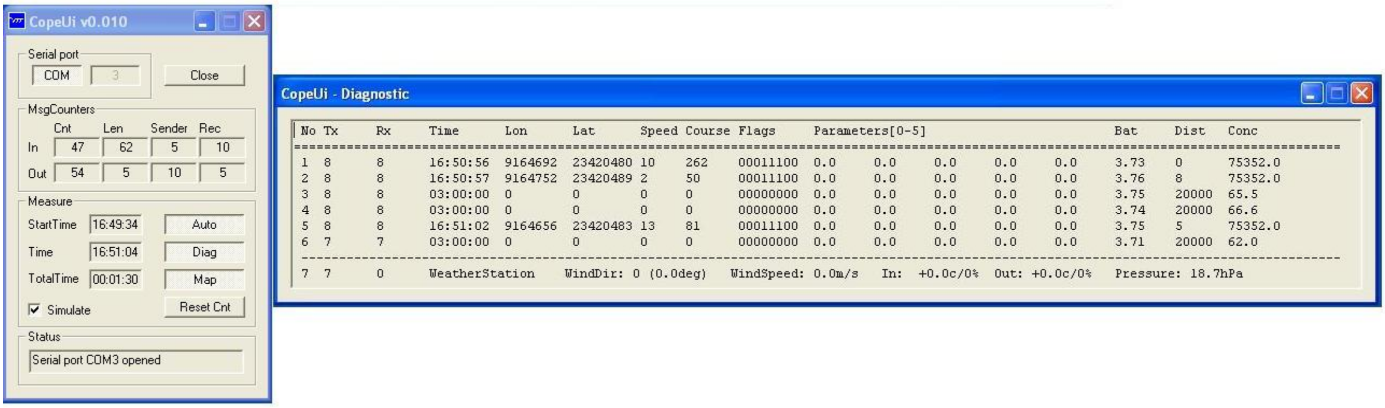

Figure 5. Diagnostic window and control panel (example data).

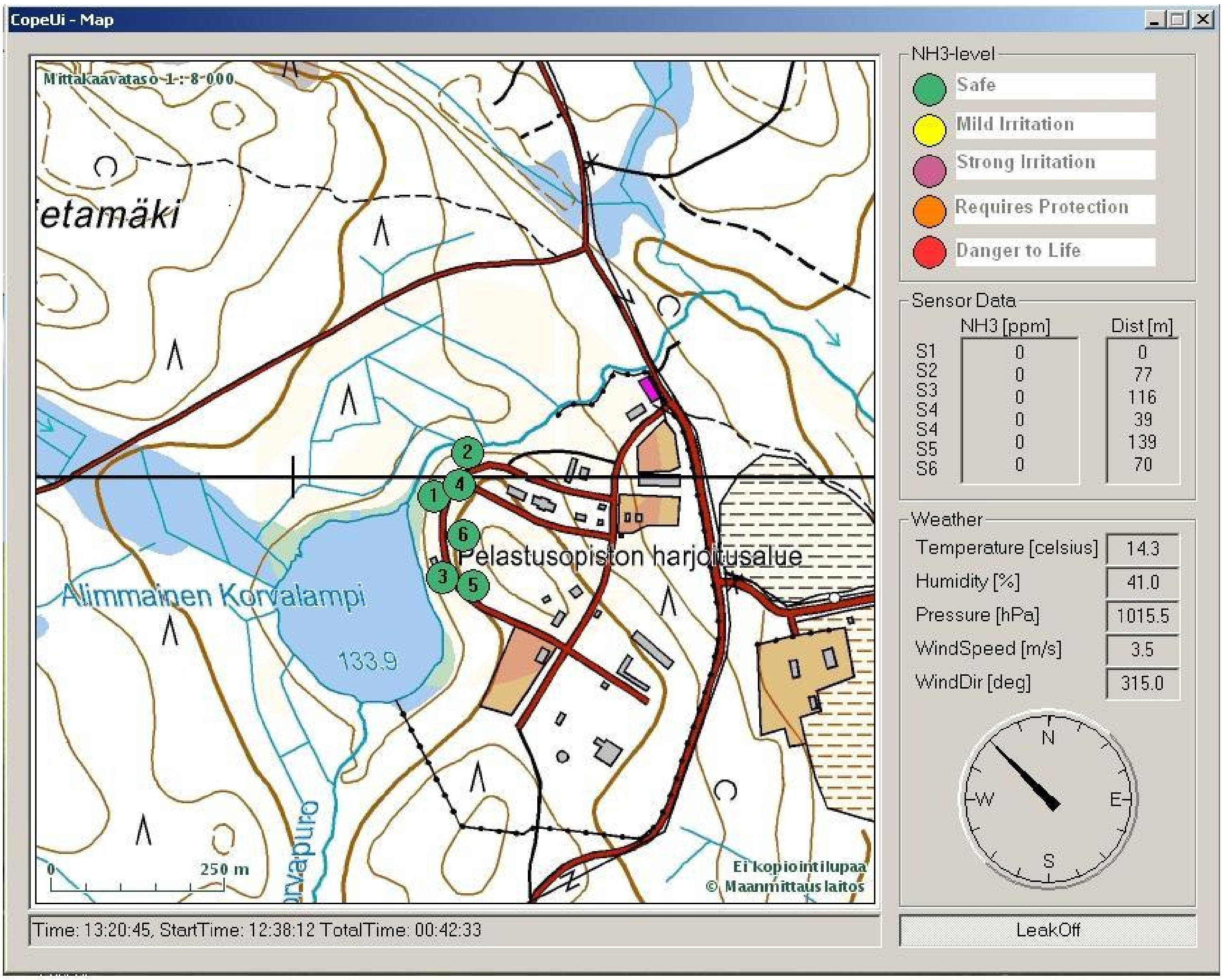

Figure 6. Main display of the software GUI.

In the GUI the data is represented in a map background. The position of the sensor is displayed on the map by a symbol (coloured circle); the colour of the symbol is changed according to the gas level (NH3 in this case). The distance between the sensors and the leak and the gas concentration is also displayed in a numerical format. The weather conditions are represented numerically and in addition the wind direction with a symbol. The "LeakOff" button is only for the simulation purposes to inform the system of the stopping of the leakage.

5.4 Research question: the changes in decision making and COP due to the new technology

The focus on Kuopio design study was on how decision making and the formation of COP is changed when new technology is used. The accomplished task analysis provided the structure of the performance as it appears in the present operations. A new testing approach that we labelled the *Parallel Augmented Exercise* was developed to study the present practices and anticipate the effect of the new technical elements on the practices (see chapters 6.2.2 and 6.2.3).

The following research questions were formulated:

1. What are the decision making demands of the Incident Commander, coping with which the Wireless Sensor Network technology may bring added value.

This question was studied by analysing the incident Commander's decision making and formation of Common Operational Picture in the present practice and comparing the result with the situation when new technical elements were available.

It was also found necessary to raise some further questions concerning the WSN technology and its further development as part of the COPE technology.

2. How could sensor technology be combined with existing technologies and information systems
3. How to develop the WSN technology solutions to better support IC activity?
4. What are the main constraints to be taken into account in the design of WSN technology for fighting dangerous substances?

These questions were studied via analysing the technical performance of the WSN in the real-like environment and via inquiring users' experience of the WSN solution available in the exercise.

5.5 Performing the design study

5.5.1 Practical organisation of the design study

The study took place at the Kuopio Emergency Services College on May 12th, 2009.

- 11.5.2009 Testing the arrangements
  - informing students (with the trainer)
  - informing the augmented team (two experienced firemen participating in further training) about its role
  - acquiring consent

- 12.5. 2009 Accomplishing the exercise

  9.00 dress rehearsal, duration about 1 hour (true test for the students)
  12.30- 13.00 Test performance (effective time 1 hour)
  13.00- 14.30 Debriefings (effective time 1 hour)

5.5.2 Human factor methods

In the next we shall describe the procedure and methods we used in the design study.

5.5.2.1 Out of the task-artefact cycle

The analyses of activities for eliciting of user requirements in usage-driven design normally focus on present activities. This brings problems because the tools and activity in which the tools are used typically change interdependently. When the designed new tools are later implemented also the activity has changed and the analysis of the user demands may be more or less outdated. This vicious circle was labelled as the task-artefact cycle (Carroll et al. 1991). To avoid finding ourselves in this trap we attempted to create means that would carry us over this dilemma. At least two methodological possibilities are open here.

The first way is a theoretical and conceptual distancing. We may develop ways of design that do not only focus on singular products and the immediate user demands that they can be connected with, as design often does. Instead design should also aim at producing more generic results that provide new potentials. Such results may be called formative outcomes of the design as they shape both expectations of the users, and create possibilities and concepts to further design. The need for this kind of design has been expressed recently by companies and designers who express claims for “research like design”, or “remote design” (Keinonen 2007). In our WSN case we attempt to reach a formative level of design by focusing on the design of the COP function. In other words we attempt to understand what the function of COP conceptually is and how it could be supported by new technology and reorganising work.

The second methodological line that may be helpful in avoiding the task-artefact cycle is more practice-related. It focuses on developing the way user studies are conducted. We may characterize such an approach to express “reflection in practice”. In this case the attempt is not only to create a theoretical or conceptual “elevator” to lift us up from the existing constraints but, instead, to take distance by creating a real open zone for innovation within the present practice. Here we use the famous idea of L.S. Vygotsky called the “zone of proximal development” (ZPD). It denotes identifying the developmental possibilities by observing (a child’s) activity when external (adult) support is provided (Vygotsky 1978).

In our context the ZPD is achieved by a special arrangement. It is not possible to test new technologies in a real activity without disturbing the learned flow of actions too much so that it is difficult to identify potentials. Hence, we test and scrutinize new technologies against a flow of real well learned actions of professional practitioners who use present technologies. The present practice serves as a background against which the possibilities of the new technology can be reflected and tested on-line with another group of practitioners. Within such an open zone, practitioners, substance matter experts, and researchers will have a chance to observe the potential of the technologies and their added value to the studied work.

In our design study we utilised both above-mentioned strategies, i.e. we conceptualised the new design target COP, and we also conducted an empirical “zone of proximal development” by making design experiments with regard to certain technologies, Wireless Sensor Networks.

5.5.2.2 Methodology of the design study – Parallel Augmented Exercise

As indicated, the idea was to create a real-like test situation in which two optional forms of emergency response activities run parallelly. The intention was to let the normal practice create a background that would enable testing the new technologies. The method could be labelled *“Parallel Augmented Exercise”*. In concrete, the idea is to let a first activity, the “Present Operations”, take place as comprehensive as possible. In our case the “Present Operations” is the ESC students’ performance when they accomplish a complex emergency response task in a real like accident situation. Parallel to the “Present Operations” (PO), a second activity was created. It was called the “Augmented Operations” (AO). It involved only two professional fire men who imagined here the role of an incident commander. For a short while two first responders from the PO group attended the AO group for spreading out sensors. The AO group was devoted to test and create ways of using wireless sensor technologies in the emergency situation that they could observe the PO group to tackle.

The AO group implemented wireless sensors in the environment, exploited the information that the sensors delivered, and considered how this information could be used by an Incident Commander responsible for such a situation. The AO group did not influence the activity of the IC of the present Operations group. Instead the AO group was advised to imagine how the information gathered would influence and support the work of the IC. The AO group was also asked to write notes about any ideas to improve work and its technological support. Careful recording of both on-going activities was accomplished by the researchers, as explained below.

Both activities were discussed in debriefing sessions after the exercise, the PO group in a normal debriefing lead by the instructor, the AO group in an interview accomplished by the researcher.

5.5.2.3 Data collection

In this section we shall describe what data was gathered from the performance of both groups, , i.e. PO and AO groups.

Present operations PO

The participants of this group were students who were in their final training phases. These students acted as incident commander and members of the fire brigade. The test involved three fire brigade units (5+1 men), one ambulance unit (1+1), and incident commander. Police service was simulated by the instructor, who also played the role of Emergency Response Centre (ERC).

Complete registration of telephone traffic was collected. The students utilised the TETRA authority network and occupying five channels: 1 channel = Emergency Cal Centre – IC; 2 channel = IC- unit leader; 3,4,5 channels = within each three units).

Video recordings were taken with two simultaneous cameras. These were focused as follows:

- overview of the PO group's activities (standing camera)
- Incident Commander of the PO group (mobile camera)

Debriefing with the PO group, lead by the instructor was also video recorded.

Augmented operations

The participants of this group were two commander course students who had experience of acting professionally as IC. Their role in the exercise was IC.

Video recordings from the command vehicle (mobile camera).

- Book-keeping template used during the test, including time, received information, and actions that the information gave rise to.

Group interview with the two professional fire men. Questions dealt with:

- What was it like to operate with the new technology
- Did you get the type of information that would have affected on decision making (- what would be the effect)
- Did you get the type of information that would have affected on emergency response (- what would be the effect)
- Would the emergency work get changed if WSN technology (wireless sensors) were used in emergency response (how could it be used, how would it be changed)

Observations concerning the use of WSN technology

- COPE project members observed the use of WSN technology and provided technical help if necessary to

5.5.2.4 Analysis of data

The design study focused on identifying and estimation of the added value of WSN technologies in a emergency response in fighting hazardous substances.

Three sets of evaluation criteria may be considered relevant in the evaluation:

a) Decision making and communication

Successfulness of IC decision making: These criteria focus on the appropriateness of the emergency response in the exercise and refer to the performance of the "Present Operations" group. The criteria are drawn from the recorded debriefing that the instructor accomplished with the PO group. The evaluation aspects and criteria the instructor used were discussed with the instructor in the preparatory phase of the study. The existing guides for IC activity and guides for acting in hazardous substance accidents were mentioned by the instructor as the frame of reference he used in making the evaluation. The task analysis described in 5.2.2 includes many of the issues the instructor articulated as his evaluation criteria.

Analysis of communication of meaning. Another level of evaluation is to identify general patterns of behaviour that portray meaning that the situation makes to the actors. At VTT we have made attempts to developed new ways of analysing activity from the point of view discovering the meaning that corporeal behaviour carries. Such analysis is needed to evaluate the communicative function of artefacts (Pesonen et al. 2008; Savioja and Norros 2008; Norros and Savioja 2009). In this connection we make a further adaptation of these analyses. We exploit here the idea that the semiotic concept of habit proposed by C.S. Peirce (1978) may be used to analyse communication processes that take place between human and environment in certain situations. As COP is considered a communicational process we exploit the habit concept to understand how meaning is communicated in the emergency response activity in the studied situation. (see also Bödker and Andersen 2005).

According to Peirce, human actors connect themselves to the possibilities of the environment by continuous action-perception cycles, during which the outcomes of action are observed. As a result, an initial state of doubt about the environment is turned into a state of belief about the environment. These beliefs are habits that embody meanings related to certain situation or objects. The role of habit is to enable interpreting the cues of the environment and anticipating the effects of own acting.

Peirce proposed that habit expresses a fundamental principle of human thought, which allows some thing to be in some way substituted or represented by another thing. Hence, *sign (S),* i.e. environmental or societal cue - the form of which is heavily dependent on the applied technological medium - denote certain *object (O) or objective*. Understanding of this relationship becomes evident via action, thought, emotion, or another act or behaviour that is an effect of the sign and its *interpretant (I).* Inclusion of the element of intrerpreation into the sign model puts emphasis on the practical aspect of signs, i.e. their use in communication of meaning in practical action. The tridadic structure that sign, object and interpretant forms is depicted in the following.

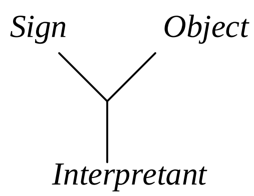

Figure 7. Triadic structure of habit formation (Peirce).

This semiotic structure may be used in the analysis of a continuous communication process (semiosis): Hence, appearance and use of signs enable denoting the aimed object and control of own and others behaviour in a situation. Moreover, action as interpretant functions as new signs and launch further behaviour connected to the object. Our intention is to use this model to study how common operational picture is formed during an emergency response situation. It is important to note that this analysis does not focus on one individual person's behaviour. Rather it is targeted to describing the communicative process that creates understanding and meaning concerning the situation. The environment, several actors and artefacts have their roles in this process which are defined by the triadic sign structure.

b) Promisingness of the new technology in IC decision making

In addition to developing criteria with regard to ER performance in the present operations it is also necessary to define further criteria concerning the added value of the studied technology. We call these criteria criteria of the promisingness of the new technology. The idea is to draw on the users' experience of testing the technology and infer how promising they feel the technology could be in a future use. In our case these criteria are needed to make conclusions about the experiences of the "Augmented operations".

c) Constraints on technologies and problems identified

It is also possible to evaluate how the technology performed in the context of the design study. We identified technical problems and evaluated the functionality and reliability of the tested technology.

- We shall exploit the above described evaluation criteria as comprehensive as reasonable in the contect of this design study. It may be foreseen that the experiences we gain in the evaluation may be used later when the evaluation methodology for the COPE demonstrations is developed.

5.5.3 Technological methods

5.5.3.1 Performing the simulation

Even though the WSN consists of several sensor units to measure the ammonia level, it would have been really dangerous to actually use realistic amount of hazardous material in an experiment. Therefore the ammonia level is simulated. The simulated values are based on estimated concentrations in described incident. The simulation data calculation is done with estimation software which uses predicting model for ammonia gas in different weather conditions. The simulated concentrations are based on the real locations of the sensors. However this technology has readiness to be used in real accidents with real sensors.

The simulation parameters are calculated by estimation software (ESCAPE, *Expert System for Consequence Analysis using a PErsonal computer*) and prediction functions derived from the program. These estimations take also the weather conditions and distance to the leak into account. In the figure 8 below the different concentrations with twelve different wind speeds as a function of distance are graphed.

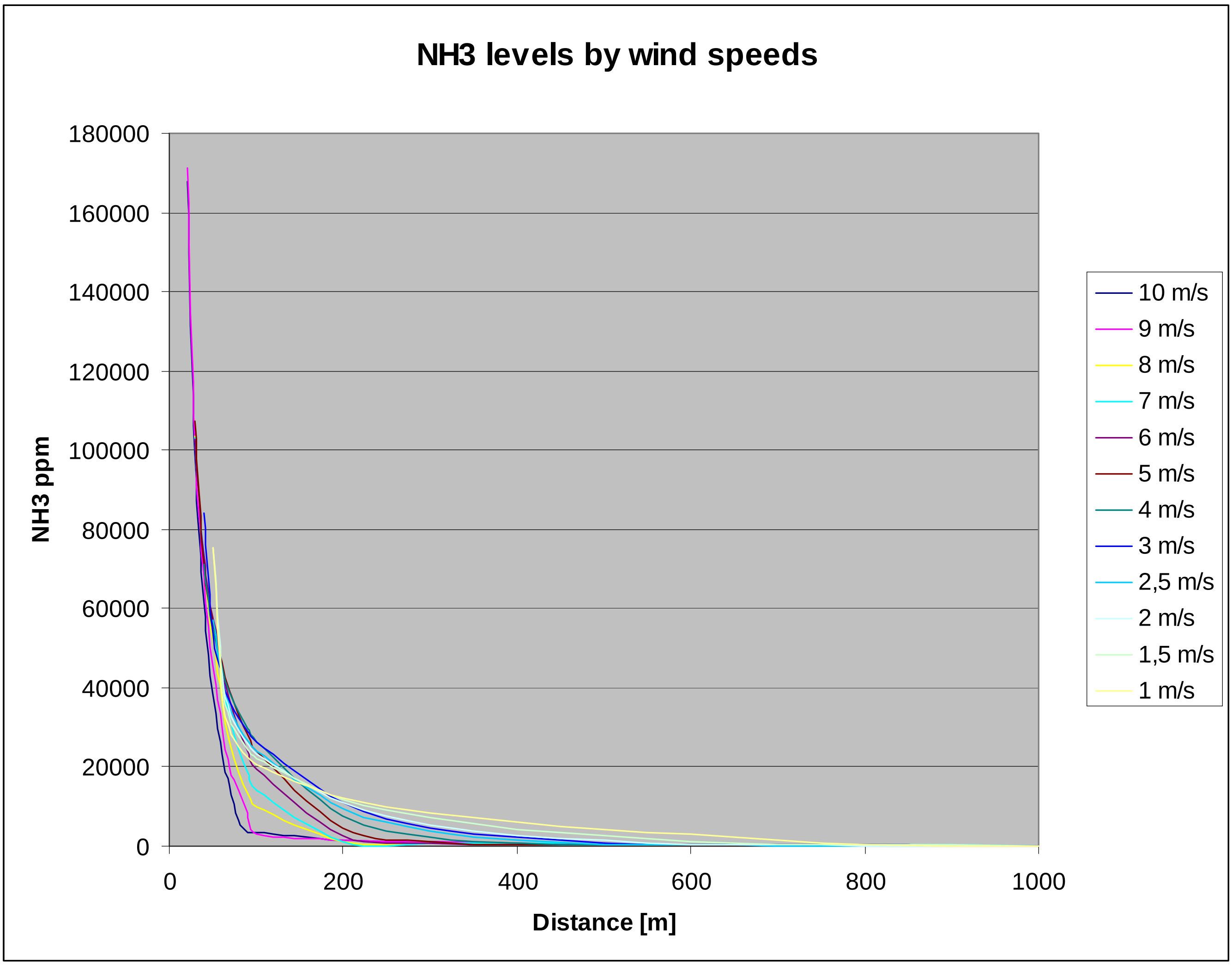

Figure 8. Concentration estimation curves for different wind speeds and distances.

In the figure 9 below, two different formulas for the decrease and increase of the ammonia level as a function of time is presented. In these functions the coefficient *k* is derived experimentally to describe the steepness of the function which is affected by the wind speed. The constant *a* is the initial value from the estimation program for the ammonia level, *t1* is the elapsed time and *t2* is the time when the NH3 concentration saturates derived by the estimation software.

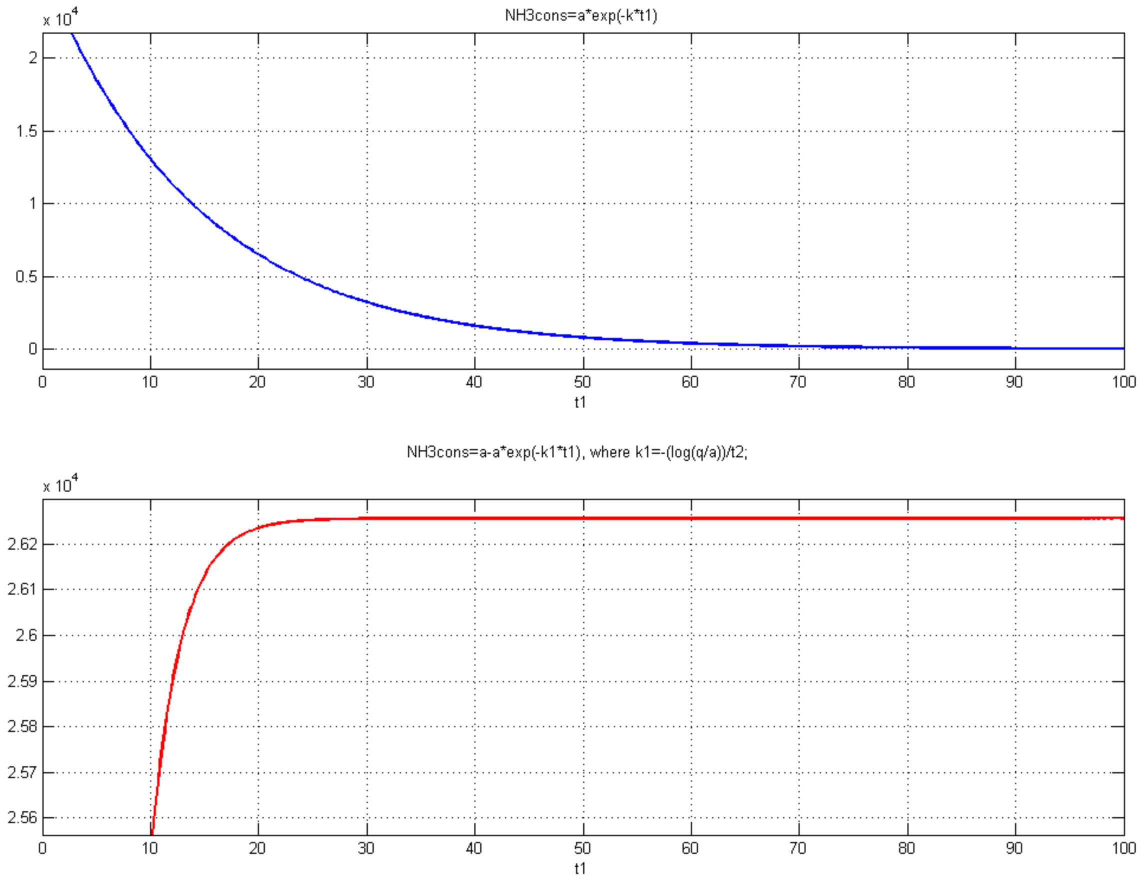

Figure 9. Simulations for NH3 level decrease due to closing the leak (upper graph) and increase until saturation (lower graph) as a function of time.

The concentration for the sensors is calculated with these three different functions and parameters described above. The lower curve in the figure 9 is used before the saturation of the ammonia in certain distance is occurred. When the saturation occurs the concentrations presented in figure 8 are used for different wind speeds and distances until the leak is stopped. When the leak stops the upper function in the figure 9 is used to estimate the decreasing of the concentration.

6 Results of the Kuopio design study

We shall start reporting the results from the technological results. In the following section it will made evident how well the prototype performed technically in the tested conditions. This section focuses particularly on the research questions 2, 3 and 4. The second section of this chapter provides the human factors analysis results. This section focuses primarily on the first research question. We provide results of incident commander's and first responders' performance in the presently typical practice and compare this with results concerning of the use of WSN technology.

6.1 Technological results

WSN was used to measure concentrations of hazardous material in the ammonia truck accident. The NH3 concentrations are based on the simulation described in the previous chapter. The feedback from the WSN is presented in the figure 10 below. The figure 7 represents the results after the sensors have been spread to the incident ground. The figure shows the NH3 concentrations for different sensors located at the incident ground as shown in the figure 4. The wind speed is also represented in the graph below. The distances to the ammonia leak are shown besides the legend of the sensors. It can bee seen from the figure 7, that the wind speed affects the hazmat level. The level is also changed according to the distance between the sensor and the leak. The GPS position error (max < 10 m) is also influencing distance estimation and thus indirectly affecting the concentration level. The affect of the GPS-error can be seen from the sensor 4 curve. The distance estimation has been varied thus affecting to the hazmat level. Furthermore, as the point of leakage is estimated by GPS and the distance of sensors are estimated relative to the leakage by GPS as well, possible distance error for each sensor is doubled.

It can be noticed from the figure 10 that the concentration level is higher the closer the sensor is to the leak. The wind speed is affecting the concentration level according to the curves shown in figure 8. The figure shows that the concentration starts to decrease after the leakage is over ("LeakOff" button is pressed at 0:10) and the curves follow the functions introduced in figure 10.

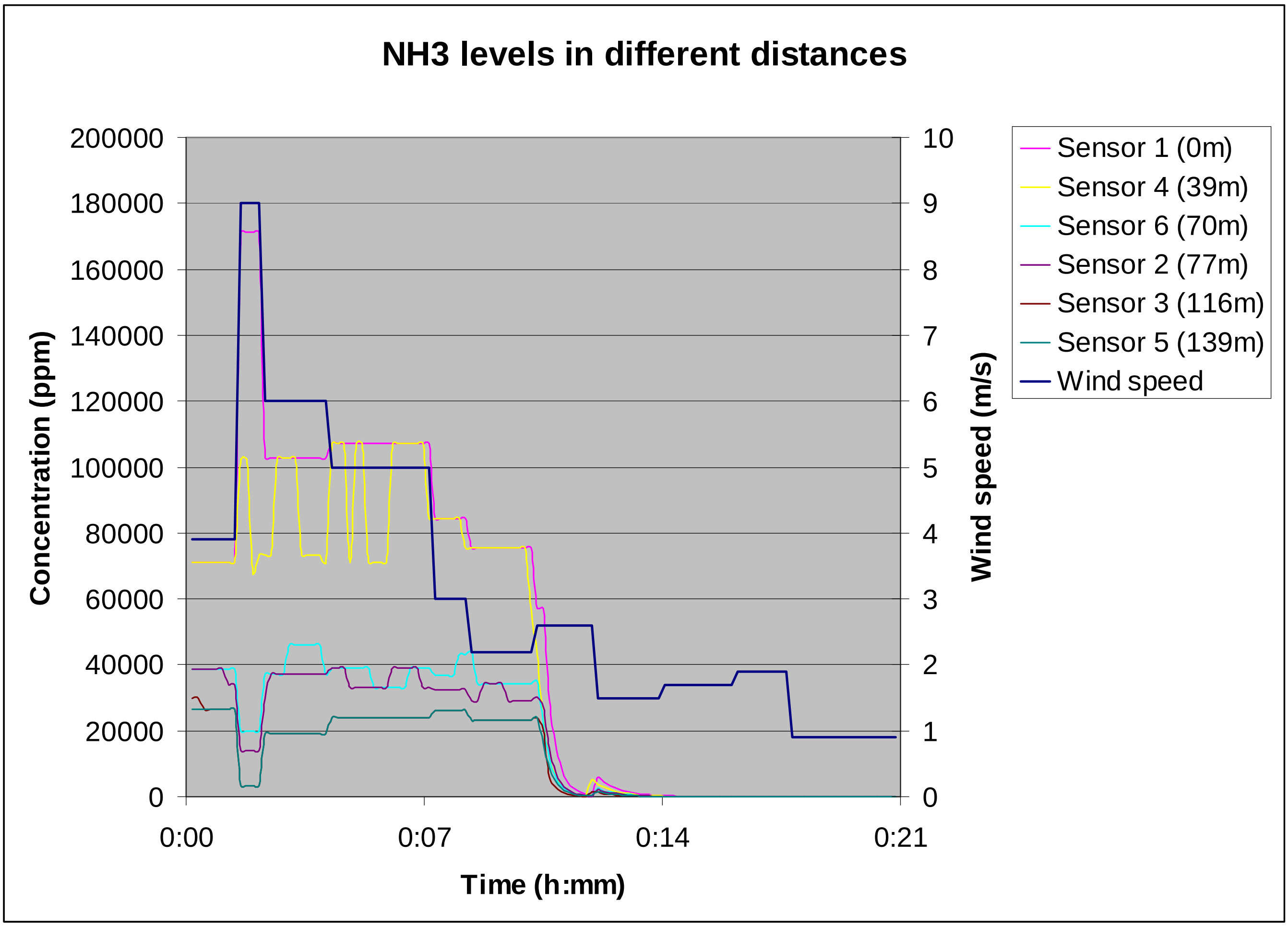

Figure 10. Experiment results. NH3 concentrations for the sensors as a function of time.

One of the objectives of the experiment was to test the used ICT in harsh emergency operation environment. Testing the reliability of the radio technology in this kind of circumstances was especially of the interests.

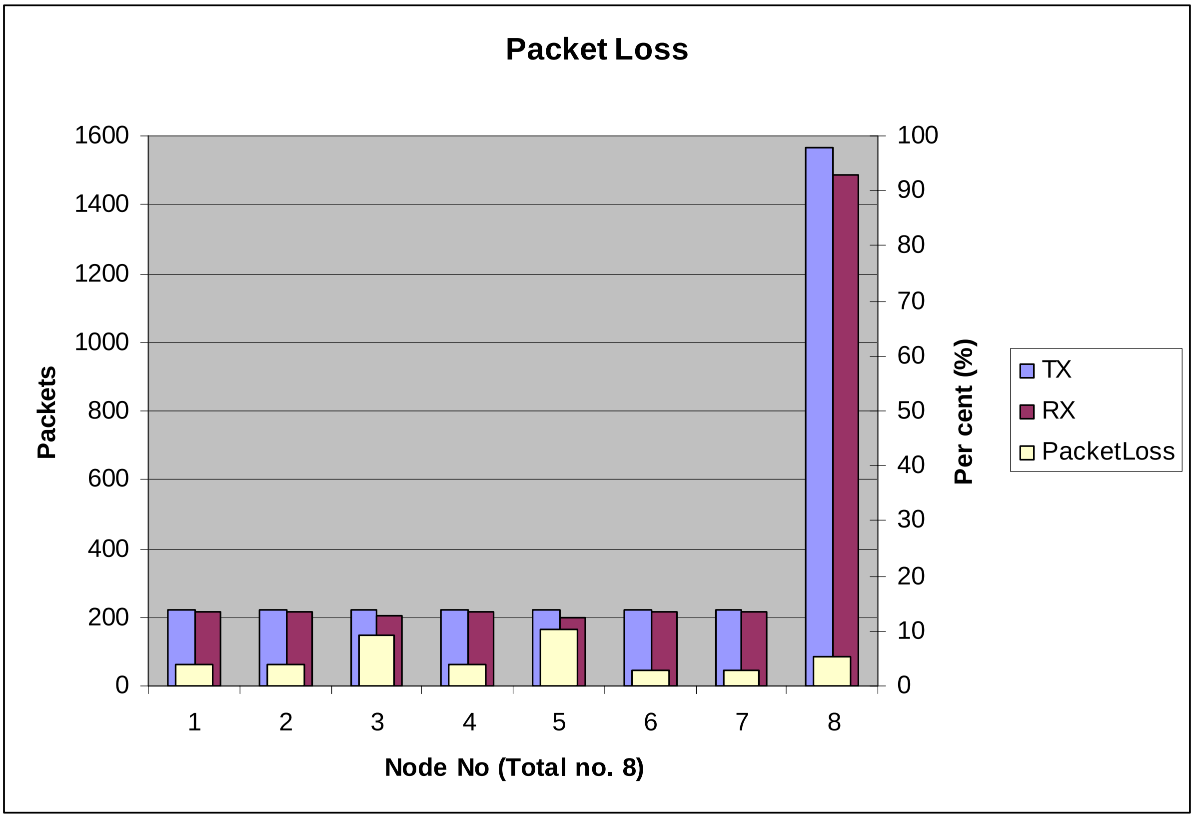

Figure 11. Packet loss transmitted and received packets.

In the chart above (Figure 11) about the packet loss, transmitted (TX) and received (RX) packets of the sensors are represented. The total transmitted and received packets and the total packet loss is in the 8th column.

The chart shows the largest packet loss is in the farthest nodes (3 and 5) and the average packet loss is around 5 %. Packet loss can be due to poor weather conditions (rain, smog etc.), obstacles such as cars, buildings and forest and also landscape formations (e.g. hills).

In the experiment, weather was quite poor due to constant albeit not hard rain. Along with poor weather, packet loss was supposedly also due to sensor locations as some of sensors were behind accident cars and additionally, the sensors that were furthest away were behind a hill. Regarding the circumstances, packet loss was quite low and the required information was received with proper frequency even though retransmissions were not used.

To summarize, the functionality and reliability of the WSN and sensor technology proved to be adequate to be used in real-like situations.

6.2 Human factors results

6.2.1 Emergency response performance in the present practice

6.2.1.1 Successfulness of Incident Commander’s decision making

Before the Kuopio study, the decision-making demands of the Incident Commander, related to this type of incident, were identified by using Finnish incident commander guidelines (Neuvonen 2007), see chapter 4.2.2. In the following it is evaluated, according to the feedback from a trainer to the students, how well the Incident Commander succeeded in decision making. The task analysis describes the main content of the information that was available for the actors during the exercise, and the sources of information. The trainer simulated the Emergency Response Centre and did not provide the actors with more ESC support and information of the accident that he considered to be available in a real accident situation.

Creation and maintenance of awareness of the situation:

Are there casualties

In Finland, Incident Commander mainly works in his vehicle, having contact with the incident site by TETRA radio talk. Accordingly, IC had ordered a fire fighter to walk around the scene. Two evident casualties were soon identified, one in the truck and another in the passenger car. When the fire fighter found that there was still another passenger car involved, burning with the driver behind the truck, it was already too late to do anything for the driver in the car. Hence, the fire fighter only told IC that a burning vehicle with a dead body inside was found.

What is the leaking hazardous substance

The symbols in the truck told in this case immediately to the IC that the substance in the truck was ammonia. This, however, should and also was verified by checking the meaning of the symbols from a handbook. The name of the substance was also reported to fire fighters by TETRA.

What is the size of the leak

The size of the leak was evaluated when chemical divers had reached the leak. They told to IC by TETRA that the size is quite large, about of a two-euro coin. The information was needed especially for closing the leak; the same chemical divers performed the closing. It could be used also for evaluating the speed the substance is spreading out from a container.

What is the direction and speed of wind, and the temperature and humidity of air

Wind properties, humidity and temperature can be asked from Finnish Meteorological Institute. The values apply for a larger geographical area so that local weather is not known unless the incident happens to be near the measurement point used by the Institute. In this case, the information of wind direction was received already when driving to the incident site but at the site, the direction of wind appeared to be unstable. Hence, no clear overview was obtained about the local weather.

What is the actual concentration and spatial spreading of the substance

Finnish rescue services have a software application named ESCAPE that evaluates the spreading of the substance according to the weather conditions. Actual concentration of the substance in the truck may be known based on documentation in the truck but the spatial spreading of the substance can only be evaluated according to some general spreading principle. The rough values are fed in ESCAPE that gives an estimation of spreading of the substance.

This time, however, ESCAPE couldn’t be launched so that no such estimate could be made. Furthermore, IC did not evaluate specifically the spreading of the substance, probably due to his inexperience.

Are people threatened by the chemical cloud

IC was aware that as the leaking chemical is ammonia, it is dangerous. He tried to evaluate the spreading of the substance with ESCAPE but when it failed and as according to the map, there was no population nearby, he did not evaluate at all its effect on surroundings. This resulted in not taking into account the possible consequences of the spreading of the substance to people in the surrounding areas not shown on the map (kindergarten locating at about 500 m from the accident).

He could have called, however, to Emergency Response Centre and tell them where the cloud is and where it is heading so that ERC could have made an evacuation alarm to local people.

Organising response activity in three sectors:

Identify the primary focus of activity and divide resources
On his way to the incident site, IC correctly ordered three teams according to general operational instructions: one team for reconnaissance and rescue tasks and one team for isolating the area and the establishment of cleansing site. When the substance was known, one team was commanded to prepare for chemical diving. The initial organisation of fire fighters, i.e. their tasking, was evaluated as appropriate by the instructor.

Initiate care of injured people
One team was commanded to find and take care of injured people and emergency response unit helped the team when injured people were found. This performance was evaluated appropriate by the instructor.

Initiate fire fighting of the burning vehicle
The fire in the burning vehicle was in the steady state phase when it was found, the driver inside it was perished and the car was far from other inflammable materials so that it did not cause any danger to the surroundings. The instructor judged that the decision taken by the sector commander to leave the car burning without any specific measures was appropriate. The IC was informed of this decision later.

Initiate chemical fighting
One team was correctly commanded to put on protection wear as chemical divers and to investigate the leak.

Definition of the immediate danger zone:

What is the needed level of protection of the first responders
First responders near the leak were commanded to perform chemical diving, which was considered appropriate by the instructor. IC ordered a chemical diving team with specific protection wear to have a closer look at the leak and to close it. However, he did not notice that the team members did not wear special gloves. If this would have been a real accident instead of a practice in which only mild concentrations of ammonia were used, the divers would have got some injury due to the cold ammonia.

Emergency medical service was not told to be properly protected so that when they started to take care of the patients, they were affected by ammonia, which would have lead to ammonia-induced symptoms if real ammonia had been used.

These deficiencies were possibly due to the inexperience of the Incident Commander, the fire fighters doing the diving and the emergency medical unit, all students in this exercise.

What is the working area where it is possible to work without breathing masks
When on the way to the incident site, IC ordered the danger zone by defining the location for the vehicles where they should park. Danger zone was set to 25 m to all directions from the leak – Command Vehicle was located at about 25 meters and other vehicles were behind it.

As the accident took place in the forest, roads leading to the accident and only a little forest were isolated. The danger zone, however, was too close as it was ammonia in question. It should have been set much further, preferably at 300 m, as the leak size was quite big and wind was not stable but alternated continuously. If a real accident would have been the case, people at least in the Command Vehicle would have got ammonia-based symptoms.

Planning of the protection zone and the protection of the population:

Using the available information e.g. the diffusion model (ESCAPE) define the protection zone
The diffusion model provided by ESCAPE could not be used as ESCAPE could not be launched. However, the protection zone was set at 200 m.

Coping with uncertainties due wind, and the specific features of the terrain
IC had no reliable information about the wind which appeared to change its direction every now and then but only the information that was given them when they were dispatched. It was, however, too general to be exact in the changing situation. The uncertainties (alternating wind) and specific features of the terrain (e.g. a nearby lake) were unnoticed.

Decision for ways of protecting population for chemical
The diffusion model provided by ESCAPE could not be used as ESCAPE could not be launched, making the estimation of population needing protection more difficult.

There was no population according to map consultation. That is why no special population protection measures were taken. However, emergency response centre could have been contacted and informed that according to estimations (that were not done) a dangerous area extends to the specified area and if there are people, they should be warned. In the exercise, a kindergarten nearby had called to the emergency response centre which in turn contacted IC. IC ordered people to go in and to close all openings in the building which was a correct act but did not order ambulance staff to protect themselves which should have been done.

Monitoring on-going response activities:

IC was in contact with emergency response centre and fire fighters in the field by TETRA radio talk. Sector commanders reported IC when the activities according to commands were performed and reported what was going on in the field, giving also interim reports of tasks they were performing. IC was well aware of the situation at the site. This required, however, dense contacting via TETRA.

6.2.1.2 Formation of COP

The description of the successfulness of the IC decision making in the previous section was based on the instructor's comments and the first responders' reactions in the debriefing session after the exercise. In order to create an understanding of how the common ground, the Common Operational Picture was created in the situation we accomplished an analysis of the observational data (field notes, video and telecommunication recordings). This analysis comprised of two steps: course of action description and an analysis of the communication of meaning during the event. As a result we expect to shed light to how COP was formed in the studied situation.

Course of action description

The starting point in the analysis was the understanding of COP that we had created so far in the project. Hence we attempted to provide a description of how the understanding of the situation developed over time as a result of action-perception cycles that the incident commander was performing while fulfilling the aims and tasks that he had in the situation. The Functional Situation Model describes the aims of the task, its main phases, functions to be fulfilled and available information. The model is a reference for analysis. It portrays possibilities and constraints not prescribed sequence, nor what really happened.

As we have also assumed that COP composes of technological elements we wanted to register which communicational and other tools were used. It may be noted that this analysis is mainly focused on communication technology and tools used in representing or storing information. The analysis is incomplete regarding the extinction technology.

The duration of the video and telephone traffic recordings of the exercise were about 39 minutes. A protocol sheet was prepared of this material. In order to structure this empirical material we drafted a process model of the communicational actions that we were expecting to observe in the material among the IC, the firs responders and the environment. The model is depicted in Figure 12.

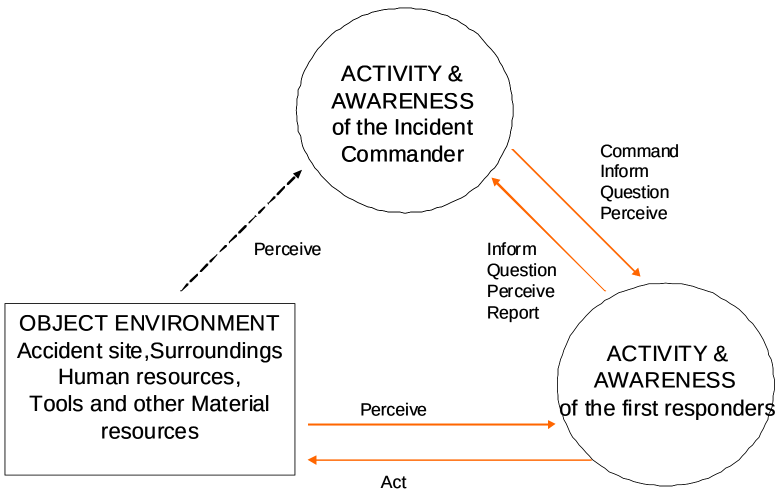

Figure 12. Model of the communication actions between the environment, incident commander and first responders during an emergency response process.

By applying this model as a frame we created a temporal description of the event. The entire description was 12 pages long, of which the first page is shown in Table 2. As the table indicates we represented the material in a temporal order. We identified phases of the course of action by making reference to the Functional Situation Model (see first column of Table 1). In the second and third column we marked IC and other actors' activities, respectively. IC activities were classified as command, inform, question actions and perceptions. Other actors in the situation were Emergency Response Centre, or first responders (indicated by the numbers of their units i.e. 018, 031, 041, and 194). First responder activities were classified as inform, question, report actions and perceptions. The IC and first responder actions and perceptions were mediated by either communication or representation media. These were indicated in the third column. In the fifth column we registered our conception of how the understanding of the situation was emerging. On the sixth column we marked steps concerning the development of understanding of the situation by the Augmented Operations group. This information was available from a vide recording of the Augmented Operations group.

Analysis of communication of meaning

In this phase we focused on the emergence and communication of meaning of the situation during the accident. The analysis took place with the help of the triadic sign model that was explained in section 5.5.2. The attempt was to see how Common Operational Picture emerged during the exercise.

As a first step of the analysis we identified episodes within the course of action that we considered important from the communicational point of view. These episodes represent steps in the formation of the understanding of the situation. We distinguished five episodes:

1st episode: Accident severity estimation
2nd episode: Decision for tactics
3rd episode: Specification of threat & definition of response
4th episode: Accumulation of problems
5th episode: Response to ammonium cloud.

In the following we shall discuss each episode. In each case we shall analyse

- what the object of communication was and how the object evolved during the episode, i.e. what content COP had during this episode?
- what signs were central in launching the communicative process?
- how widely shared the object was?
- what media were involved in the process?

Purposes and functions (on the basis of the Functional Situation Model FSM)	IC (Command, Inform, Question, Perceive)	Medium (communication and representation)	ERC or First responder (Inform, Perceive, Question, Report)	COP Present	COP Augmented
0 min **Alarm**		Mobile telephone	ERC: Q: truck driver calls for help S		
Call centre-IC:	P: The emergency call made by truck's driver, contact lost during the telephone conversation. Apparently a collision btw a truck and two passenger cars. No information about a chemical or possible casualties O	Tetra ERC/IC	I: Relatively big accident; address; units to dispatch 031, 041, 018, Kuopio 914		
	I: Informs all units about the accident C: Stop at "Siilo": I	Tetra IC/all units	P: No reply	Shared but incomplete information about the accident. Reconnaissance started already during the approach to site: wind direction. Initial plan for sectorization made.	
	C: Stop at Siilo	Tetra IC/all units			
	I: At site. Communication with ERC channel 1-1 S	Tetra IC/ERC and all units	P: Stop at "Siilo" I		
3 min	(Ammonium tank-possible leak??) O	White board: Dispatched units Main tasks and responsibilities of units I	P: ERC and all units: P: Status of IC, communication channel changed.		
3 min **Reconnaissance:** *Search for information *Accident severity estimation	O C: 031 immediate danger zone 25 m, task type: reconnaissance and rescue, protection wear fire costume, breathing mask I	White board: "Ammonium" identification numbers 268, 1005 (from the truck sign) I Tetra IC/ 031 Driver: Ammonium White board / task type; completes responsibilities	P: 031 acknowledges, informs protection wear to be used I		

Table 2. First page of the course of action protocol sheet. Indicated are also the elements of the communication analysis: S=Sign, I=Interpretant action, O=Object, state of the environment.

1st episode 1: Alarm and accident severity estimation

The first episode is depicted in Figure 13. This picture is a transformation of the material from the course of action sheet in Table X. The letters and dashed boxes in this table refer to the sign model used in the analysis. The fraction of the sheet in Table 2 demonstrates the analysis of the 1st episode.

We identified first events or messages that could be considered as *signs* that had an important message to deliver in the course of actions. These are always indicated as the left branch of the sign model. Together with the sign we also identified the *communication medium* that was active in delivering the message of the sign. The left box on the top of the figure indicates these two elements of analysis. Next we made an attempt to infer what could the *object* of the sign considered, i.e. to what target or idea concerning the state of the environment the sign referred to. This is indicated on the right branch of the sign model. The right box on the top of the figure denotes to the object-element and also to the *presentation medium* that is active in representing the object. Finally, we identified the action, or thought that could be considered as the *interpretant* of the sign, i.e. what action could be seen to indicate that the meaning of the sign had been captured by one of the actors. This is indicated in the lower branch of the sign model. Together with action we identified possible *tool or instrument* that was active in connection with the interpretant. The middle box on the top of the figure indicates this element.

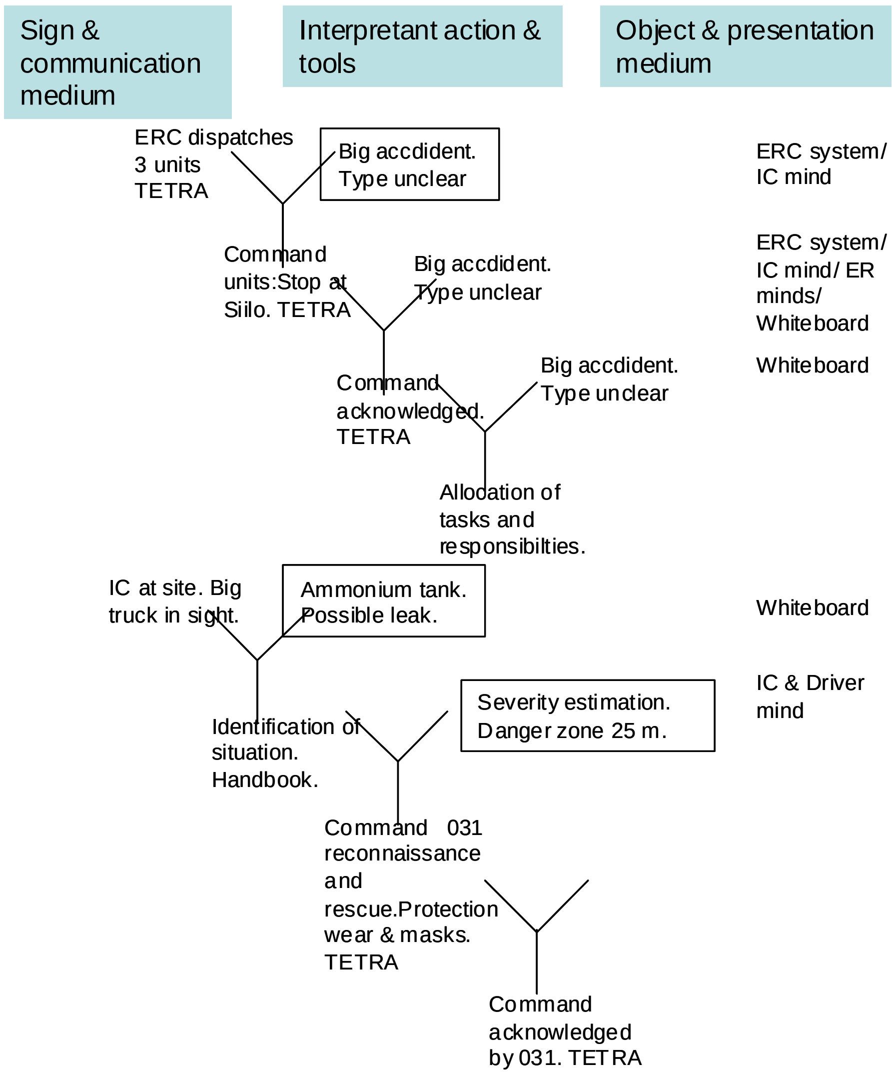

Figure 13. Communication analysis of the 1st episode “Alarm and accident severity estimation”.

The interpretant is the connecting link in the communicative process as it serves as a sign for a next step in communication chain. In many cases the communication did not continue, or it was disrupted and continued after some time lag. In the first case just one sign symbol is to be seen, and in the latter case we have indicated the postponed connection with a dashed line.

In first episode, that took place during the first 3 minutes into the event, we may observe the initial phase of the emergency response activity. The object of communication in this episode was the occurrence of an accident and its severity. The object was first comprehended as a large accident but the type of it was unclear. During the episode the nature of the accident became clearer, and the severity of the accident was comprehended via expectation of an ammonium leak that required 25 m protection zone.

The signs that were central carriers of information in this episode were first the alarm by the Emergency Response Centre (ERC). The sign is here taken rather broadly and we see that it also contained the dispatching of three units according to a predefined scheme. This sign mediated the message of large accident of undefined type. The actions launched were command the dispatched units to where to stop at site, acknowledgement of this command and allocation of responsibilities to the commanded units during approach to the site. These actions manifest that ERC, IC and all the units (018, 031, 041) shared the same understanding of the situation.

The media used in the first phase of the episode were TETRA radio network for communication. Presentation medium was the ESC system, the minds of IC and the first responders, and also the white board in the command vehicle on which the IC started to write down his command concerning the allocation of resources to different sectors of the response.

In the second phase IC has proceeded to the site. The accident scene and the big truck is the sign that launches the further communication chain. Especially the tag used for indicating the chemical the truck is carrying is informative. In this case the tag was clearly visible from IC's position were the command car was parked. Visual communication medium was in use. The symbol of the substance is 268, 1005. The object is elaborated as the hand book available in the truck is consulted by the driver, and the substance in the truck tank is identified to be ammonium and a possible leak may be expected as a consequence of the collision. This objective is further shared with the unit 031 which is commanded for rescue and reconnaissance wearing protection clothes and breathing masks. These actions indicate the adoption of a more precise conception of the accident situation and its severity.

As a result of the second phase of this episode understanding of the situation is deepened and two more agents are sharing the view, i.e. the driver and the unit 031. The specification of the situation is not communicated back to ERC. Two more media are exploited, visual communication of the sign and the hand book for interpreting the sign while identifying hazardous substance.

2nd episode: Decision for tactics

In the analysis of the second episode we utilise the same scheme as with regard to the first episode.
In the second episode the course of events had proceeded. The episode took place between the 3rd and 4th minute into the event. Three units are entering the accident site (see Figure 14).

The object of this episode is the understanding of the different emergency response demands in the situation and conceptions of tackling the demands. The object is in the first phases of the episode comprised of the ammonium danger and the necessary danger zone it requires. Later in the episode more aspects enter into the conception but the tactic remains focused on the ammonium danger.

The initiating sign of this episode is the information from the unit 031 that the substance is ammonium. The Incident Commander had observed the tag on the truck from the Command Vehicle. This message is confirmed by the IC and the agreement of the object also. The confirmation of the IC leads triggers the driver to further confirmation which is portrayed in his further consulting the handbooks. The specification of the danger zone is especially focused and the joint understanding is 25 m which is also drawn on the white board.

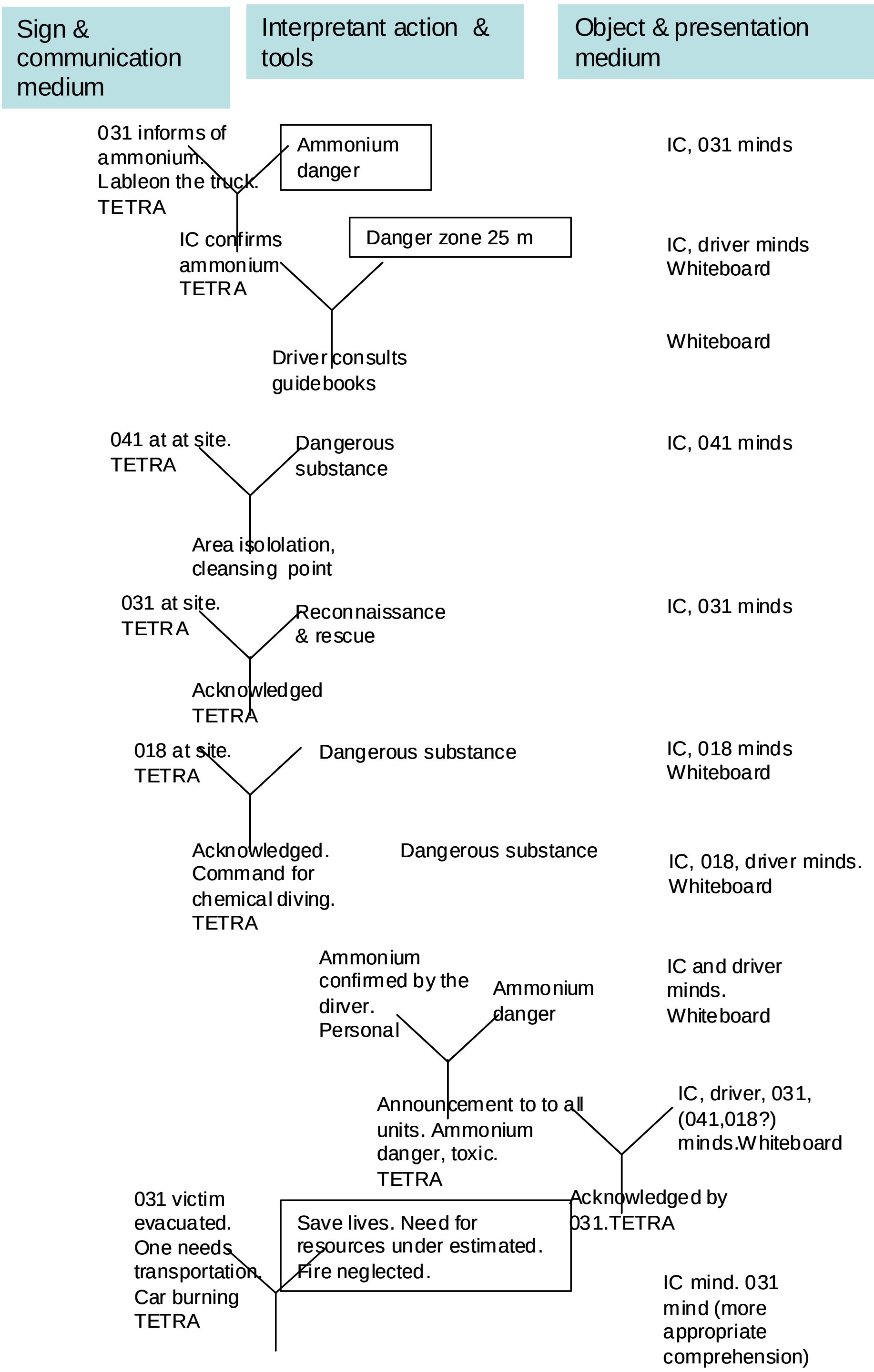

Figure 14. Communication analysis of the 2nd episode “Decision for tactics”.

At this stage the IC, driver and the unit 031 share the understanding of an ammonium danger. The extension of the danger zone is not shared with 031. TETRA network is continuously an important communication medium but sight is also used. The guidebook enters again as an instrument. The representation media are agents' minds and the white board.

In the next phase all the three fire fighter units report being on site. These reports serve as separate signs to the IC to launch actions and define the object. Unit 031 was already commanded for rescue and has adopted it as an object. This unit is also aware of the ammonium danger, as IC and the driver. The two other units 018 and 041 receive their command, the first to chemical diving and the second to isolation. By these commands the units become aware of a dangerous substance object. TETRA is used to communicate and the representational medium is the minds of these agents. The white board also represents the allocation of resources to these units.

The command to chemical diving triggers a final confirmation of the type of the dangerous substance as the driver once more confirms this with the IC in their discussion. The shared understanding of an ammonium danger is manifested by the interpretant action by the IC to announce the ammonium danger to all units. This understanding should now be shared by all active agents, and it is also presented on the white board. One acknowledgement from 031 is received.

In the last phase of this episode the unit 031 brings new information of the situation. One victim has been transported, evidently there are more, and there is a car burning. This sign indicates a need to save lives and extinguish fire but according to the action of IC this message does not appear to be mediated fully to the IC. It may be concluded that the focus of the emergency response is clearly on the ammonium danger and all units are aware of this focus. The unit 031 is acting more or less autonomously in rescue and fire fighting sectors.

3rd episode: Specification of threat & definition of response

The third episode is depicted in the next Figure 15. Again the same method is used to analyse the communication process. This episode took place between 7 and 11 minutes into the event.

The object in this episode is characterised by a need to define the ammonium threat in more specific terms and to develop a specific response to tackle the problem.

The initiating event of this episode is the proposal of the driver to the IC to get more information about the ammonium leak. The communication relies on personal contact. The IC adopts immediately the idea which becomes overt in his request to unit 031 about the leak. An immediate answer is delivered which states that the hole in the tank side is about the size of a 2€ coin. This further understanding of the size denotes the need to do something about it but this understanding is not mediated further because IC action is disrupted for a while.

The attention of the IC is drawn by the sign of the ambulance unit entering the site. TETRA radio is once more delivering the message. The IC has maintained the need for transportation of patients in mind and now has a chance to command the 194 to get ready to receive victims from the site. The unit 194 acknowledges the command which may be taken as unit 194 adoption of the shared object of patient transportation. As a continuation of this communication IC orders the 194 unit to take responsibility for the medical care. The formation of the object does not include the connection to the ammonium threat as no indication of this is made to the unit 194. This means that this unit is not prepared to this danger when getting ready to transporting patients.

A further TETRA mediated sign is the unit 041 as it informs of having completed isolation of the first road. The unit proposes continuing isolation task. The object is isolation but no mention of the second object of preparing a cleansing place is mentioned by either the IC or the unit 041 even though this second objective was included in the initial command by the IC.

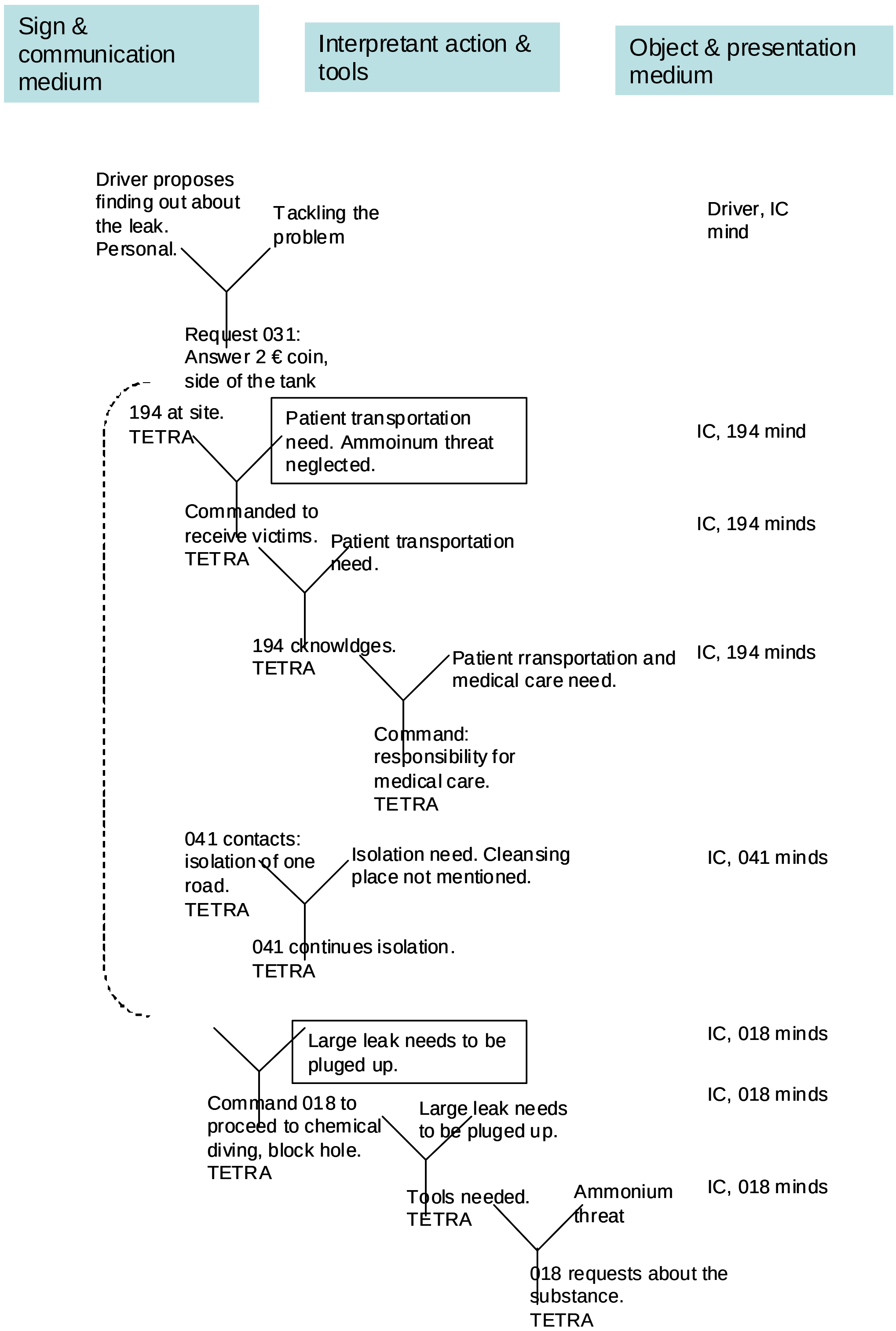

Figure 15. Communication analysis of the 3rd episode “Specification of threat and definition of response.

In the next phase IC picks up the pending sign informing about the size and place of the ammonium leak. This becomes evident in the command to unit 018 to proceed to chemical diving and to block the leak. The command speaks of the object of understanding the leak to be considerable size that needs to be blocked. TETRA telephone carries the messages, as usual in this event. As 018 acknowledges the command it also proposes the use of certain tools and hence indicates of adopting IC's object. However, it becomes clear by the next action of the unit 018, i.e. a request about the hazardous substance, that understanding of the ammonium threat was not complete. The instructor returned to this issue during the debriefing and it was assumed that probably the unit was getting dressed in the chemical suits when the announcement about the ammonium danger was made, and they did not hear the TETRA mediated information. This was not known to the IC until at this phase.

The analysis of the communication process during the episode 3 indicates that the focus of the IC was on the ammonium as the pervious episode already was indicating. The emergency responders working in the sectors of the emergency response, i.e. fire (in the previous episode), and isolation and medical care in this episode, did not become sufficiently aware of the requirements of the ammonium threat. Only the unit 031 had acknowledged the announcement concerning the threat. The complex object including all the different sectors and their interactions was not really developed. The object was represented partially in the minds of the IC and the driver. The units 194, 041, 018 had special targets but would have required better understanding of the ammonium threat in accomplishing their tasks. Unit 031 had rather good understanding of the situation and they acted independently in the sectors that were not in the focus of IC attention.

4th episode: Accumulation of problems

The next, fourth episode took place between 12 and 24 minutes into the event. The object of this episode is to understand the comprehensive emergency response needs of the event. All units dispatched to the event are now active. During this episode the immediate ammonium threat was solved but further problems arose (see Figure 16).

The initiating event in this episode is the contact from ERC over TETRA radio informing of toxic symptoms by children at the nearby kindergarten. This sign was considered to denote a minor health problem and the IC advised to take the children inside and shut down the ventilation system. The driver was anticipating more severe problems and need for more focused attention but this idea, which becomes evident in his attempts to consult maps and guide books to clarify local area and possible measures for warning population, was not considered by the IC.

The attention of the IC is drawn by one of the unit 031 emergency responders who comes personally to IC to discuss the problem of water supply. IC responds by saying that no maps of water supply are available. 031 also informs of the burning car, and with regard to the response by the IC it appears that he had so far not been aware of this problem.

Soon also unit 194 contacts over TETRA and informs of transporting a second patient. The IC reminds of the units independent responsibility for medical care and transportation. He is not referring to ammonium at al. Some time later unit 194 addresses the question of cleansing place. Meanwhile ESC has joined the transportation and medical care sector in communication by announcing of dispatching a second ambulance to the site. Later unit 194 becomes patient in waiting the ambulance and also requires help for transportation of patients. It becomes slowly evident that the object of transportation has been comprehended too narrowly both with regard to the extent of service and also with regard to the protection needed to handle patients. IC, ESC and 194 all share the need to elaborate their conception of the situation.

Units 031 and 041 both inform of anticipated short of water. This information is given both over TETRA and personally to IC. The fact that there are no maps about water supply is repeated but no further commands are given concerning how to handle this serious problem. Unit 041 made independent attempts to find water and contact IC with a proposal of drawing hose lining from the distance of 200 m. As the water supply was still half a tank and IC had meanwhile the information that the ammonium leak was blocked, he did not consider extra water line necessary. At this stage, neither of the units 031 and 041 new how the chemical divers (unit 018) proceeded in blocking the leak.

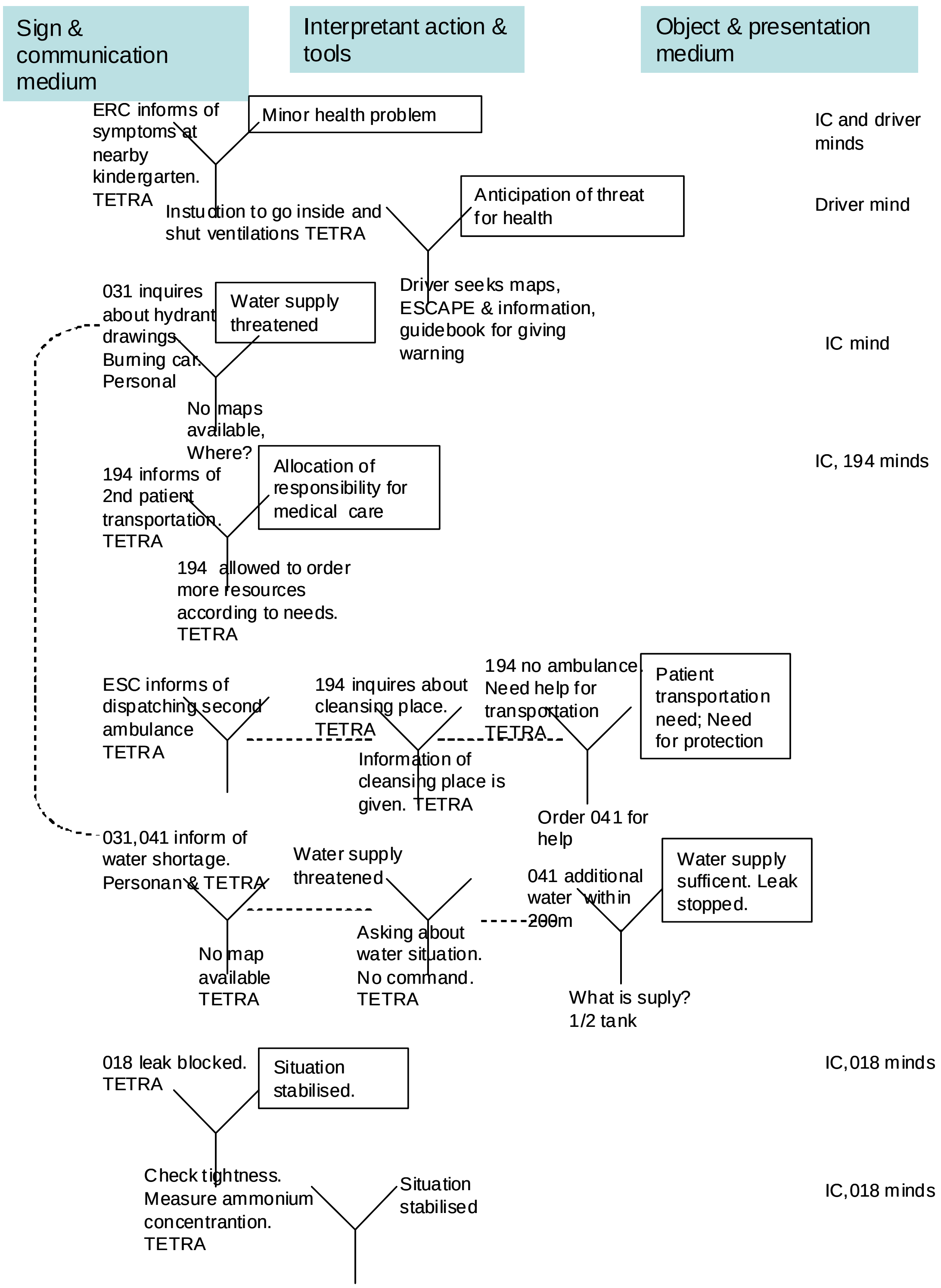

Figure 16. Communication analysis of the 4th episode "Accumulation of problems".

The unit 018 informs of having blocked the leak. The tightness of the block is asked to be checked and as this has been accomplished the situation is considered to be stabilised. This makes sense as the immediate threat of ammonium has been the focused object in the event. Yet it appears that all emergency response units have identified problems that suggest that the object should have been defined more broadly, i.e. considering more comprehensively the medical care and its interaction with the ammonium problem, the fire, the water supply sufficiency and the spreading of ammonium cloud.

TETRA telephone was used appropriately in communicating singular messages from different sectors. It appeared however that when the object of communication becomes more complex and interactions between sectors are necessary TETRA is not sufficient. First responders tended to seek personal contact with IC. The need for and power of dialogue was also demonstrated in the successful collaboration between the IC and the driver. The latter made several important contributions to improve the situation. The white board did not play any role when the situation got more complex.

5th episode: Response to ammonium cloud

The final episode we identified took place toward the end of the exercise, between 30 to 37 minutes. The overall object of this episode is the understanding of the spreading of the ammonium cloud and the health threat caused by it (see Figure 17).

The initiating event, and sign that starts the final communication process, is TETRA call from ERC. It concerned the toxic symptoms of which children of the kindergarten still are suffering. The object to which this sign is connected to is minor health problems that would, however, soon disappear as the ammonium leak had been blocked. According to this object IC orders the ambulance service to approach the kindergarten without protection wear. ERC comprehends the problem to be more severe, and requests about the safety of the ambulance personnel. IC reacts to this message and contact unit 018 at the site asking for measuring of the ammonium concentration level. As the answer is provided and the result showing non–toxic levels, and after the tightness of block was checked, IC considers the situation to be safe. He orders the unit 018 chemical drivers to withdraw.

In this episode the object i.e. the target or idea concerning the state of the environment that the signs were considered to refer was clearly too restricted. The report of the instructor’s debriefing indicated that IC and the driver did not succeed to make the technical means, the ESCAPE system available that could possibly have helped to understand that the cloud was much more dangerous than what they had imagined. The experience of the first responder students was not sufficient to compensate the lack of this information. It must be noted, however, that as chemical accidents are rather rare it is possible that also more experience fire fighters could have similar difficulties to comprehend the actual quite severe threat of the ammonium cloud.

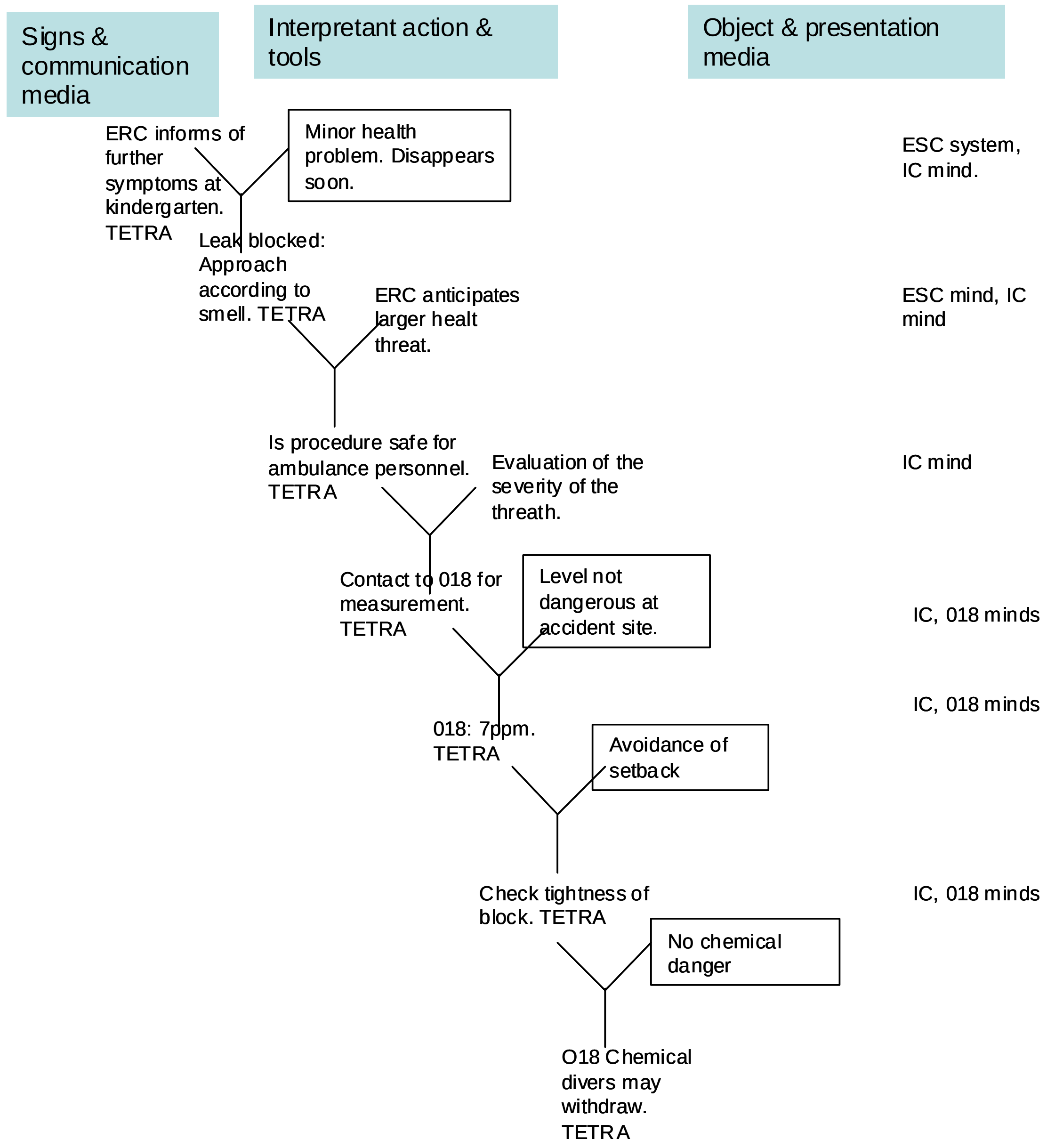

Figure 17. Communication analysis of the 5th episode "Response to ammonium cloud".

Conclusions concerning the formation of COP

In the previous COPE definition of COP (see section 2.2) a structural point of view was dominant. We shall return to this aspect below (section 7.3) but shall first discuss the communicational point of view to COP that we adopted in the analysis.

<u>*COP as a communication process*</u>

As was already indicated in Chapter 2, a communicational point of view would be fruitful in developing the COP concept. It is connected with the idea of understanding how common ground is created among actors who are expected to act in a coordinated way in emergency response situations. We started the communication analysis by a communication process model in which we indicated the types of communications that we expected to identify in the empirical material. The model used was depicted in Figure 12 above. Using the elements and interactions of this model as an analysis our frame we prepared a temporal description of the course of action.

In the next step of the analysis we then transform the data into understanding of the propagation of meaning during the event. We applied a particular communicational approach that utilises a semiotic triadic model proposed by C.S. Peirce. This model describes the communication process between the environment and human actors, i.e. it explains the process of making sense of the environment and the on-going event. The analysis allows considering both human and technological elements as contributors in the communication process. In the analysis we distinguished the emerging conception of the state of the environment (object), the signs that denoted to the object and launched the communication process. In the communication process certain actions indicate that the sign has been understood (interpretant). With the aid of this structure communication and sense making chains could be identified on the basis of the available behavioural data (see Figures 13-17). These analyses made evident how the IC and the first responders, step-by-step accomplished their work, and how actually the outcomes of action of which the analysis of the successfulness of decision making came about.

In the process of creating and communicating meaning technological and other media play a central role. In our analysis we identified three types of media: communication media, instrumental media i.e. tools, and representation media. The analysis provided description of the role of these media in the studied communication process, i.e. in the formation of COP. These different media types are a central element of the structure of COP (see below).

Empirical findings of COP

What would then be the concrete findings of our communicational analysis concerning first responder performance and the formation of COP in the studied circumstances?

The role of the IC in the communication chain

The role of the IC in the communication process was of course central. This follows from the prescribed responsibilities and tasks of an IC. Yet, important elaborations of the IC's communicational behaviour could be made. Information flow from the IC to him was continuous and affluent. According to our analyses the IC's interactive actions with the first responders comprised mainly of command, informing, question and perception actions. At the same time it became clear that the IC's interaction with the environment and the phenomena taking place in the event is highly mediated and indirect. The IC's understanding of the situation was based on the information he received from the first responders or other actors of the system, e.g. Emergency Response Centre via TETRA radio network.

It was also clear that very often the active partner in the communication was the first responder from the field, due to the fact that the later had information concerning the accident and the environment or his and his group's task performance and resources. It might be that there exists also a more proactive ways of commanding the situation, but still we see that the essence of the IC´s role is to keep up with the dynamically changing environment, of which the first responders have on-line information.

The IC appeared to be the agent who played a central role in *formulating the understanding of the situation*. Understanding could be inferred on clear statements and communications but always also from actions that were performed. It became evident, however, that at many points of the event the first responders of different sectors had a leading role in the creation of the understanding. In some cases the joint understanding of the situation did not reach that of a sector leader and his group. We also found that the driver of the command vehicle was a very important help for the IC in the forming of the understanding of the situation. This person was for example searching background information from books or using the computer ESCAPE computer programme. The analysis indicates that in several instances the driver introduced new action possibilities, offered assessments of the situation, confirmed hypotheses, and monitored IC´s performance. This contribution significantly supported IC's work. Our results indicate that the formulation of the understanding of the state of the environment is a dialogical process. Possibilities for such a dialogue should not be impaired when new technologies are introduced. Making data available automatically does not substitute constructive dialogue in the formation of COP.

Our study indicated that in many phases of the emergency response, defined tasks and roles can be accomplished by first responders as rehearsed and rather independently. In such a stage of the IC did not appear to have difficulties to create and mediate an understanding of the situation. It was partly not even necessary because the rehearsed routines were sufficient to anticipate the proceeding of actions. The challenge is that there is however always *interactions and more complex objects/objectives* have to be created jointly by the sectors. Need to comprehend such interactions and make connections between functions was difficult for the IC and the formation of COP was insufficient.

We also found that IC easily *focuses on temporally and spatially local* problems. It appears that anticipation in time-space is a feature of behaviour that would require support.

Another significant difficulty that we observed in the IC work was *disruptions*. In many of the studied episodes we found moments where several tasks were run in parallel.

The activity of the first responder in the communication chain

The first responder is directly connected to the environment with operational actions. The primary instruments they are using as tools in the response tasks are the major communicational media among first responders' themselves. The role of these media, e.g. the role of ropes and hoses for communication, were not studied in detail in this exercise but it would deserve more detailed analysis. It is also possible that some deliberately communicational elements could be added on these instrumental artefacts.

Currently the first responders are mainly relying on their natural senses in making observations of the environment. From debriefings and interviews with first responders we gained the understanding the extension of the natural senses to improve the perception of the environment are useful. Infrared camera was widely referred to as a real improvement in the equipment of the first responder. It appeared also that the identification of chemicals and portraying their concentration was found to be technological development that would be found useful in practice.

The first responders, while acting physically on the environment gain continuously information and understanding of the state of the environment. The first responders in the observed exercise were actively informing of the IC about the state of the environment over the TETRA telephone. In some cases, when there was need to dialogue with the IC, first responders came personally to the command vehicle to discuss with the IC.

The role of different media

Communication media: TETRA telephone network was the clearly most important communication medium in the exercise. Direct speech also played important role in the case of solving problems.

Instruments and tools: The results did not support the idea that IC or his support tools should be moving around the accident ground. Rather we observed that it was necessary for him to maintain in his base and focus on comprehending the situation from distance and make his orders from there. Mobility is important, however, in a wider sense: It was observed that during approaching the site the IC anticipated the forthcoming tasks and made preparations concerning them. Such anticipatory tasks would in some case benefit from mobile connections beyond the already now available well function TETRA telephone network. On the basis of our results it would appear that technologies that would improve the facilities of the command vehicle, e.g. larger screens equipped with different functionalities that enable divere views to the environment.

Our exercise drew attention to the need for orienting frames during the incident command. Geographic information, maps etc. or also target-related background information could be very helpful. A temporal frame would also be useful as well as task-oriented frames.

Representation media: A clear result of our study was that the understanding of the situation, COP, was mainly represented in the human minds. Only a fraction of this understanding was brought to an external medium. White board was used only in the first phase of the exercise. When the situation became more complex and diverse this medium was not used any more. On the other hand, it was exactly then, when keeping track of the situation and modelling it would have been beneficial.

Books and handbooks played an important role in the exercise. They were used continuously and without any interface problems. Several books were open simultaneously which indicated a need for parallel use of the material. A computer-based system for calculating spreading of chemicals in the environment was available for use but IC and the driver did not succeed to get it started.

6.2.2 Emergency response performance with new technology

6.2.2.1 Added value of WSN for Incident Commander decision making

Above, in chapter 6.2.2.1, evaluation of how critical decision making demands were met in the study by operations that are performed by current state of the art was presented. Now such points are raised in which the new technology could have supported decision making. Only such demands are specified that the new technology (WSN) has some impact on. The data for the evaluation originates from video recordings, communication recordings and interview of the Augmented Operations group.

Creation and maintenance of awareness of the situation:

Are there casualties
No effect of the new sensor technology.

What is the leaking hazardous substance
If sensors were able to identify several substances, they could be used in many incidents where hazardous material is involved. They could be used both for identifying the substance and, if several mobile sensors were used, for evaluating the diffusion of the identified substance. Then, the substance identification would not be so heavily dependant on the visibility of symbols, information possibly written at the substance container or the documents related to it.

In this study, substance identification was rapid so that the new technology would not have had any effect on it.

What is the size of the leak
No effect of the new sensor technology.

What is the direction and speed of wind, and the temperature and humidity of air
WSN technology has weather unit attached so that local weather is known when using it. This is important when hazardous substances are involved as local weather condition can be different from generally known, officially delivered weather information.

In this study, no clear overview was obtained about the local weather so WSN technology would have made a major difference in showing it.

What is the actual concentration and spatial spreading of the substance
WSN technology measures the actual concentration of the substance in specific locations and shows wind direction. This information can be used for making estimates of the spatial spreading of the substance and, if needed and is possible, mobile sensors can also be taken to further locations to certify the actual concentration there.

In this study, ESCAPE could have offered an estimate of spatial spreading of the concentrate, based on estimated wind direction and estimated substance concentration. WSN technology, however, would have expressed all these values based on facts and not estimations, offering dependable information. Furthermore, it was impossible to launch ESCAPE which shows that the usability of ESCAPE is not as high as needed. A reliable device that is always functional and is easy to use could be very important in incidents where dangerous substance is possibly leaking.

Are people threatened by the chemical cloud
WSN technology expresses the quality factor of the substance as well as wind direction on a map covering the incident area. If the map is up to date and could be zoomed in and out as needed and if the application would be designed to estimate the spreading of the substance in the surrounding area, it could be very informative in showing the probable threat of the chemical cloud on population in these areas.

In this study, the new technology used was not designed to show any estimates on substance spreading in the surrounding areas but it did show actual concentration of the substance in certain locations and actual wind direction so that the probable spreading could have been made according to that information.

On the other hand, the kindergarten in question was actually only invented for this study and would not have existed in any official map so in that sense the technology would not have made any difference. Hence, IC could have called the ERC anyway to inform them about the cloud and its estimated direction and speed and ERC could have initiated evacuation where needed.

Organising response activity in three sectors:

Identify the primary focus of activity and divide resources
No effect of the new sensor technology.

Initiate care of injured people
No effect of the new sensor technology.

Initiate fire fighting of the burning vehicle
No effect of the new sensor technology.

Initiate chemical fighting
Once the substance is known, the way to perform chemical fighting is known. Hence, at this point there is no effect of the new sensor technology.

Definition of the immediate danger zone:

What is the needed level of protection of the first responders
When the leaking substance and its spreading are evaluated, the level of protection is determined. WSN technology could have shown reliable information about the chemical and its concentration at and near the accident if mobile sensors were used. This would have shown directly what the extension of the danger zone is.

In this study, danger zone was far too limited so that the new technology would have improved the situation significantly. Additionally, as a minor improvement, the new technology could have shown the level of ammonia concentration on the injured people, helping in deciding what protection should be worn when treating these people.

What is the working area where it is possible to work without breathing masks
WSN technology shows the grade of the substance in specific locations by indicating the harmfulness of the concentration level on the display on a map interface. This would be direct evidence of what to wear in the working area instead of decisions based on estimates.

In this study, danger zone was far too limited so that the new technology would have improved the situation significantly, making the danger zone to extend appropriately.

Planning of the protection zone and the protection of the population:

Using the available information e.g. the diffusion model (ESCAPE) define the protection zone
At present, protection zone is defined according to estimates. WSN technology shows real concentrations so that protection zone could be defined according to the real situation when using the new technology.

In this study, protection zone was set at 200 m. It is not known whether the definition of protection zone would have been affected the usage of WSN.

Coping with uncertainties due to wind, and the specific features of the terrain
At present, Finnish rescue services have no other means of coping with the above mentioned uncertainties than experience-based estimations. WSN technology shows local wind direction, helping in these estimations.

In this study, the direction of wind was constantly changing, so WSN technology could have provided useful information for decision making.

Decision for ways of protecting population for chemical
The better the actual level of danger, based on dangerous substance concentration, is known, the more effective are the measures to protect the population. Currently, ESCAPE is used in Finland, providing estimations on substance diffusion, whereas WSN technology shows the real concentrations of the substance in specific locations. That information, combined with the information of wind, also provided by WSN technology, offers better possibilities of population protection when efforts could be focused on locations that really need protection.

In this study, the diffusion model provided by ESCAPE could not be used as ESCAPE could not be launched. WSN could have been used to show where the chemical is presumably affecting. In this case, IC was partly misled as when looking at a real map, there was no population in the surrounding areas. However, for exercise purposes one kindergarten was "found" – in this, WSN could not help. When the ambulance was driving towards the kindergarten, IC could have informed the crew about self protection as WSN would have shown that there is chemical cloud in the location where the kindergarten is.

Monitoring on-going response activities:

No effect of the new sensor technology on current activities. If WSN technology would be used, mobile sensor spreading could be monitored by looking at the map interface, where the sensors are (and what is the chemical concentration at that location).

6.2.2.2 First responders' experience of the new WSN technology

The promisingness of the new technology is evaluated by rescue personnel who have experience of the rescue work and who have access on both acting according to the present operations and on the new technology, i.e. the Augmented Operations team.

When arriving to the incident site, Augmented Operations team put the computer on. It delivered immediately valuable information as it showed wind direction and speed, both important as they affect the procedures to be done and because this is the only way to be informed about the local weather. If the direction of the wind changes, one can be abruptly thrown into a dangerous situation.

- Up to date information about local wind was valuable to obtain as it is important to evaluate as realistically as possible the extension of the substance in the surroundings.
- Weather station could be permanently attached to the Command Vehicle so that local weather would be readily available – in the study, weather station was set up beforehand on a roof of a nearby building
- The use of the computer software was very easy: it was easy to start to use and while using it, there was nothing that the user should remember. This was found very important as in the hasty and demanding situation, no more load in the form of secondary tasks (operating the tools) should be put on IC.

In the study, two fire fighters took the sensors and put them to the locations they were told to put. The locations were shown on a map and it could be seen the exact desired locations were not reached but they were positioned well enough so that no new settings were needed.

- Sensor spreading required here the use of two fire fighters. The less human resources are needed the better so the optimal way of delivering the sensors to the field has to be studied - for instance, one fir fighter could carry a sensor around the scene and that would leave a trace on the map interface about substance concentration along that path.
- Sensor spreading should be started as early as possible so that sensor information would be available already in the beginning of the rescue services. In the study it took 7 min for the fire fighters to start sensor spreading (duration calculation starting from the minute the Command vehicle is at the incident site) which is a realistic delay
- Also finding the correct location was proved demanding, at least in forest where no address can be used. On the other hand, the correctness of the location is immediately apparent and it can be corrected if needed as the location is shown in a map interface.
- Sensors were steadily standing in forest in the study but in urban surroundings, a proper stand should be designed so that sensors could stand on asphalt and other hard surfaces as well.

- One sensor could have been put near the Command Vehicle – in the study, the vehicle was too near the leak which was unnoticed. In this study, ammonia which has a distinctive odour was used but in many other substances, there is no odour to indicate the presence of some dangerous substance.

Sensors along with weather information provide important information about the concentration of the dangerous substance. This information can not be substituted in any way – evaluations that are based on theoretic assumptions, such as ESCAPE that is used in Finland, are vague and may sometimes be even misleading.

- Now IC would have real information about substance concentration in various locations.
- Substance information is readily available, also in changing situation, so that only a glance to the map interface is needed to get a general view about the situation from the substance point of view. This contrasts the use of ESCAPE which requires constant attention.
- Substance information is correct; it does not require interpretation, contrasting the use of ampoules, one option to use in current operations. Hence, the possibility of human error is diminished with the use of sensors.
- User interface was found good: The impact of the dangerous substance, expressed by the colour of the sensors in the map, was found informative by experienced fire fighters (Augmented Operations team)
- The level of protection needed for the fire fighters is easily evaluated.
- The roads to block can be easily evaluated when looking at the map interface with sensor information.
- Media can be easily informed about the areas in which gas masks or the like should be used because substance concentration is so high there, and about the areas where protection is recommended as the wind appears to blow the substance to that direction
- When the leak is blocked, it is known how substance concentration decreases and an appropriate timing can be given regarding the duration of area isolation.

Some other viewpoints were raised in addition to the ones related with the use of the technology in the study. The new technology should be combined to present digital management system. At the moment, Finland has a map interface already which makes the adaptation easier. Command Vehicle could have one sensor attached permanently so that local information would be readily available. The minimum number of sensors to be sent immediately further in the field could be two to be set 100-200 m below the wind. More sensors could be set when more fire fighters were at the site.

The greatest bottleneck in the use of the WSN technology was that its use employed human resources in a situation where every fire fighter is valuable.

As a new idea, the Augmented Operations team thought that this kind of sensors could be permanently attached near chemical factories, railway stations and other locations where chemical accidents most likely occur. Information of theses sensors should be readily available to Incident Commander’s digital systems so that whenever something deviating has happened, Incident Commander has immediate access to that information.

6.2.2.3 Constraints on technologies and problems identified

What appears to be the main constraints to be taken into account in the design of sensor technology for fighting dangerous substances? This question was raised partly by the Augmented Operations team and is partly reflected by the authors as well, as follows:

- Availability of human resources: hazardous material fighting is resource intensive

  - placement of sensors should not require too much ER resources
- User interface must be simple and intuitive in order to be easy to use in a demanding decision making situation
  - good visualisation of the measurement results from the field in the user interface is needed
  - in current design study, the impact of wind on spreading of the substance could have been more clearly marked, for instance by an arrow indicating the wind direction on the map (suggestion made by experienced fire fighters)
- Uncertainties of the diffusion model in making realistic predictions
  - dependability of the overall system (sensors, network, interface) is important
  - training is needed so that users understand the limitedness of the information given by the predicting technology
- Sensors must be reasonably prised
- Specificity of sensors – impossible to have sensors for all substances; selection of specificity of sensors

7 Discussion of the results of the Kuopio design study

7.1 Incident Commander decision making in present and augmented operations

Present operations/ media: Tetra, white board, driver, guide books, ESCAPE, maps, personal contact	**DM demand**	**Augmented operations/media**: WSN and map-based UI, heard IC reasoning and Tetra traffic
• Focus on immediate danger and operations to stop the leak • Diffusion was not conceived appropriately	Creation and maintenance of SA	• Immediate danger conceived • Diffusion of the cloud and protection of population conceived
• Three sectors established • In two sectors insufficiencies to maintain proper actions (burning car, water supply)	Organising response activity in three sectors	• Instructed sensor implementation; identified need for re-placement of sensors
• Approached close to target, did not reconsider the distance; • Danger zone not clear => protection of FRs inadequate	Definition of the immediate danger zone	• Need to increase danger zone was identified • Need to establish a clear border identified • Adequate protection of FR identified
• Insufficient anticipation of the spreading of the cloud, insufficent planning of population protection	Planning of protection zone and protection of population	• Realistic picture of the threats
• Heavy telephone traffic, difficulties to monitor all on-going activities, partly reactive responses	Monitoring on-going response activities	• Not involved

Table 3: Comparison of decision making between present and augmented operations groups.

The actual performance of the two teams in the Kuopio Design Study, Present Operations team and Augmented Operations team is depicted in the Table 3. As can be seen from the table, the WSN technology was of considerable value for decision making in the chemical accident (compare the columns between present operations and augmented operations). The team with the new technology did not participate in the actual operations so no valid evaluation can be made about which team performed better. However, if the truly performing team, (Present Operations team) would have had WSN technology in use, it would have had remarkably better prerequisites for better performance – just in those areas that were currently poorly handled.

7.2 Promisingness of the Wireless Sensor Network technology

Promisngness of the Wireless Network Technology application is in this final chapter evaluated according to Systems Usability criteria developed at VTT for evaluating the expected appropriateness of complex technologies in their future usage. A comprehensive metrics has been developed for Systems Usability evaluation (see Pesonen et al. 2008; Savioja and Norros 2008; Norros and Savioja 2009). The evaluation framework draws on the idea that the technology must be evaluated in the activity system context it is going to be implemented. In the design phase the activity system context either does not exist at all or undergoes changes as the technology changes. Therefore we apply a functional modelling approach with the help of which the demands of the future work may be anticipated. These demands are the context-specific criteria of the evaluation of systems usability. We also apply a second set of criteria which are drawn on generic functions of tools in human activity. These functions are the instrumental, the psychological and the communicative function.

Instrumentally WSN technology was effective in its performance as a tool. It was designed to measure and express weather and substance concentration in specific locations, which it performed well. It expressed clearly the concentration as a level of harmfulness the substance causes to people. This information is important in incidents where dangerous substance is involved. It is also easy to use: when the sensors are put on their locations, nothing has to be done but the information is readily available on the map interface.

When considering the *psychological function*, i.e. the technology's fit to human use and its ability to support human being to control his or her own reactions, the technology was functional. The important substance-related values (concentration of the substance in each sensor location) were expressed in a way that is intuitive to understand. As red means danger and green safe level of concentration, the meaning of the colours in between can be understood according to their location in the interface, as the equivalence between colours and their meaning is shown in the right corner of the interface.

This information can also be directly used for actions in that situation. The explicit location of the sensor put on a map interface is natural and easy to understand. If the location of a sensor is not suitable, it is easy to be traced as it shows on the map interface. Hence, corrective actions are easy to make and the new location is readily visible as well as sensor location is continuously shown in real time on the map.

On the other hand, information of wind direction was not found easy to understand. At present, it is indicated by numbers and a line aiming to a certain compass point. This way the user has to mentally transfer the information on the map. Furthermore, wind direction is not explicit as the compass bearing could indicate the direction where the wind blows from or where it blows to. This deficit could be compensated by expressing the wind direction otherwise, for instance, by an arrow located on the map, showing explicitly and with no interpretative errors the wind direction.

The technology supports *communicative function* as it mediates the purposes of actions within rescue practices. By expressing clearly the level of danger for people in the chosen locations at the incident site, the technology supports decision making concerning safe acting in dangerous environment. It supports fire fighters protection by helping in setting an appropriate danger zone and helps in specifying what to wear as an appropriate protection in the incident site. It also helps in aiding possible victims of the incident as sensors can be used to measure the amount of the dangerous substance near the victim. Furthermore, it helps in protecting the environment by showing where the dangerous substance is leaking, hence pointing where the danger-mitigating or danger-removing actions should take place.

7.3 Input to the concept of Common Operational Picture

In chapter 2 we discussed some conception of common operational picture COP. We also gave the tentative definition that the COPE project agreed in an earlier phase of the project. We all see that the concept is an important tool in developing new technologies that would improve emergency response work. The definition of the concept is not a straight forward task, not least because it refers both to technology and human behaviour and is dependent on the context of use, the end-user domain. Clearly, if we can develop a good concept it could serve as a "boundary object" and mediate joint understanding of some central phenomena of the studied first responder activity.

The attempt of this report was to develop the concept of COP on the basis of the empirical material that we had gained during the COPE human factors work (WP2, WP3 and partly also WP4). In the following a short account is made to reflect on the advances we see that this paper has made concerning our understanding of the concept f COP. We see that COP should be focused from two points of view: from communication process point of view and from structural point of view.

7.3.1 COP as a communication process

We see that the definition that we formulated in D2.1 still holds: COP is the description in time of the emergency situation that supports the emergency responders within and between different agencies to act appropriately. We also wrote that we have taken the primary functions of the COP as supporting the development and maintenance of common ground and the support of coordinated action among agencies.

The step that has been taken in this report is that we have defined the support of a common ground to be a communication process that is on-going during the emergency situation. In this report we have looked at the communication process from the perspective of how certain communicational actions facilitate interaction between the environment and the actors of the system. This model was shown in Figure 12. On the basis of this model - and there are also optional versions of process models that we could and maybe should use (e.g. proposed by Rob Hutton, see slides in DOHA) - it is possible to analyse courses of actions in various emergency response situations. This is how we used the above mentioned model in this study and created a temporal representation of the event in the Kuopio study.

In the process of analysing our empirical data we came to the conclusion that a process model is just a first phase of understanding the communication. Upon that we need still to construct the process of propagation of meaning in the situation. This process portrays the emergence of the common ground and the COP. In this case we need to use a semiotic model that is capable of representing the meaning of information that is communicated in the process. The triadic model of Peirce was used here. The attempt to use Peircean sign model in representing COP in the studied situation is explained in section 6.2.1.2.

7.3.2 COP structure

The other achievement that we think we have made in this report is to define the basic structural elements of COP. These are not defined in terms of technology but in terms of functions that are necessary for COP.

One of the benefits of the triadic semiotic model is that it connects easily with technology. As we indicated in our analysis of formation of COP in section 6.2.1.2 the elements of the model the Sign, Interpretant and Object can be related to three types of media. Sign was in our case connected to *communication media*, interpretant to *instrumental media* or tools, and object to *representation media*.

These three media types are significant elements of the COP structure.

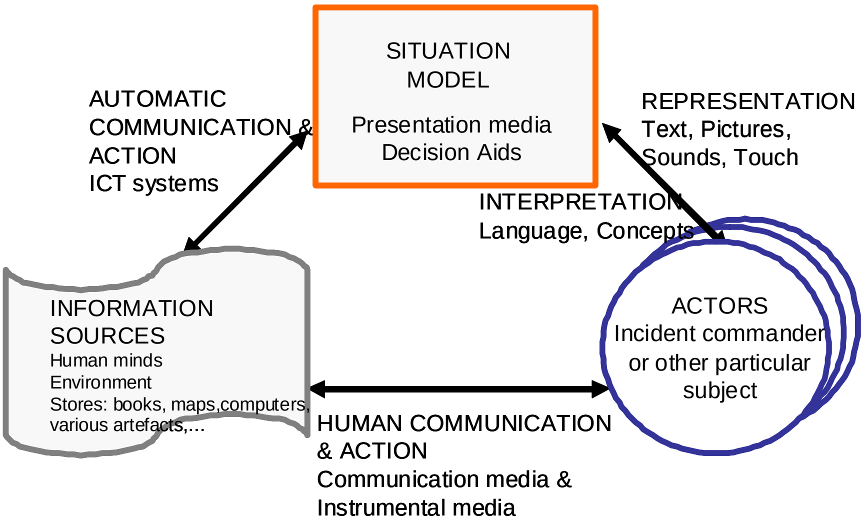

Figure 18. Basic structure of COP.

The above mentioned media types are included in the basic structure of COP that is depicted in Figure 18. We propose that the three main elements of COP, independent of the technologies that are used, are

- Situation model – external representation of the situation that is actively created via interpretation and representation activities of the human agents
- Actors – human agents who both act upon and perceive the environment and deliberately create a situation model
- Information sources - various forms of information that must either be acted on by human agents or that may automatically deliver information to the situation model.

Diverse media are needed to enable actions, to communicate with the environment and among agents, and to present the situation model.

We have also indicated the active processes among the elements in the model: Automatic communication and action, human communication and action, and representation and interpretation.

8 COP-driven requirement definition

The final chapter of this report is just a promise and plan for future work. During the WP2/3 we made an attempt to develop a set of user requirements that should be input to the technology development. So far the empirical data and experience we have gained during the COPE project have been incorporated to a task-driven user requirement analysis. We have analysed the primary and secondary tasks of first responders and inferred requirements that could support their accomplishment. The deliverable 3.2 has the important function to define the design basis for the COPE technologies.

It is our hope that it would be considered beneficial to develop some complementary requirements to the already existing ones that would emerge from a COP-driven perspective. These requirements would not be task or situation specific but would portray the generic functions of communication and meaning formation that is present in every activity of the first responders and in all situations in which they act. In this connection a more comprehensive use of the collected international interview data of IC and first responder activities should be accomplished. If this would be considered a worth while activity it would be possible to infer and deliver to the technology developers two sets of rather generic requirements, i.e. “communication process requirements” and “structural requirements of COP medium”. As a result the user requirements of the system would be composed of three kinds:

1. Task requirements i.e. requirements that relate to accomplishing role-determined primary and secondary tasks of first responders in different situations
2. Communication process requirements i.e. requirements that relate to ways of communicating and constructing a common understanding of the situation. Communication process takes place among the human actors in their different roles and the artefacts they use.
3. Medium requirements i.e. requirements that focus on all the different but intertwined aspects of the COP medium: the instrumental medium, the communication medium and the representation medium.

A further task that should be accomplished by the Human Factors group of the COPE deals with the risks and problems concerning the new technologies that the end users expressed throughout this study. Results of such considerations could be input to the development of realistic concepts of operations in the future.

Summary

Introduction
As was indicated in the introduction, the purpose of this document was to facilitate the COPE project's comprehension of the Common Operational Picture (COP). COP is the central concept of the project but as can be found in the literature there is no single definition of COP. The concept has a technical origin in the military domain where it was considered as a common format of information exchange. The concept may also be connected to the human factors perspective. Then COP denotes an emerging and interpreted conception that is dependent on operational goals. In human factures literature there are several concepts that correlate with the COP concept. Examples of such concepts are Situation Awareness (SA), team sense making, or common ground.

Background
In the present report our point of departure was the definition of COP that the project had taken in its earlier deliverables:
"COP is the description in time of the emergency situation that supports the emergency responders within and between different agencies to act appropriately. The primary functions of the COP are supporting the development and maintenance of common ground and coordinated action across actors.

COP is described as the pool of information

- that is registered and <u>stored</u> in a database
- that is available for <u>presentation</u> in a user interface suitable for emergency responder work <u>content</u> of which is structured around operational processes of the emergency responders
- <u>that needs to be interpreted and acted</u> upon by the emergency responders
- that is meaningful in the <u>context</u> of emergency responder work."

In COPE the common operational picture is foreseen to be achieved technically as a combination of various kinds of enabling technologies. These are: first responder equipment, wearable information appliances; decision support, background information; command and control system, support for IC tactical and operational decision making; sensors, augmented perception of environmental and first responder states; and wireless communication technology.

The big issue in the project is to accomplish an integration of these different technologies, and to verify the added value of these technologies to the emergency response activity. In this report we considered these questions with the aid of a particular "design study", in which the integration of sensor technologies and wireless communication technologies were tested and their added value to first responder activity studied.

Material and methods
The human factors groups of the COPE project had created a background for the design study by interviewing first responders in three European countries UK, Ireland and Finland. A joint approach and method had been agreed to accomplish this task and to create comparable data. Part of this material was utilised in the formulation of the user requirements in the D3.2 (especially the UK and Irish data), and another part (especially the data from Finland) was used in the present study a background of the design study.

The notion of "design study" refers to an innovative study the aim of which was to create a real like usage situation in which new knowledge of the needs and possibilities of new technologies could be experimented, and the added value evaluated. While innovative in character we still wanted that the study would provide experience that may be structured and reflected upon. Hence, it was necessary to create conceptual and methodical means for data collection and analysis of the results.

The design study was conducted at the Kuopio Emergency Services College in Finland as a joint activity of design engineers, end users, and human factors experts. Twenty graduate fire fighter students and two refresher trainees participated. The simulated accident situation involved a truck carrying an ammonium tank crashing with a passenger car. This accident resulted in an ammonium leakage into the environment. Immediately thereafter a second passenger car hit the truck and the passenger car caught fire. There were three victims, of which one was lost. Due to the spreading of an ammonium cloud an alarm was received of children from the nearby kindergarten to suffer of toxic symptoms. Three first responder units, one ambulance unit and a police unit (simulated) were sent to the accident site. The incident Commander (IC) commanded these units on site. Also the Emergency Response Centre was involved.

To study the activity of the IC and first responders in the described situation particular test design was constructed. It was labelled “parallel augmented exercise”. The aim was to explore added value of the wireless sensor network (WSN) technologies and new ways of working by reflecting the present situation in the light of the possibilities. The design composed of two activities that were running in parallel:

"Present operations" was composed of the first responder and IC performance as trained for such accidents, and of the use of standard instruments. No intervention was made to this performance, except that it was videotaped. Also the instructor's debriefing after the exercise was videotaped in order to capture an expert evaluation of the successfulness of the performance during the incident.

"Augmented operations" was the second activity that was observed. It was composed of the activity of two experienced fire fighters, who acted in the IC function parallel to the on-going “present operations” and tried to exploit sensor information that was made available for them. They had the task to reflect on the usefulness of this additional information in the on-going operations. Also the activity of the “augmented operations” group was videotaped. This group was interviewed afterwards concerning the use of sensor technology.

In the analysis of the collected data two perspectives were taken: First, successfulness of incident commander decision making and added value of sensor technology (task oriented), and second, communication of meaning among the multiagency ER company.

Results

Incident Commander Decision Making:

As reference in the analysis of the IC decision making we utilised the decision making demands identified in the task analysis conducted in the preparation of the exercise. We analysed the successfulness of the IC decision making in the “present operations”. Several problems were found in the IC decision making: IC under-estimated the required immediate danger zone as he did not have a clear conception of the ammonium concentration; IC focused on immediate danger and did not anticipate the problems due to the diffusion of the hazardous substance into the environment, nor the spreading of the ammonium cloud; Finally, IC had difficulties in organising and maintaining control on the response activities in all the emergency response sectors he had established.

With regard to the “augmented group” we studied whether the group gained of the sensor information with regard to the same decision making demands. The idea was, however, not to make a real comparison between the two groups, as the “augmented group” was focusing just on the use of sensor information and did not accomplishing the whole emergency response activity. Our findings indicate that the “augmented operations” group understood better the severity of the immediate ammonium danger. Hence they would have established a much larger danger zone, and they would have paid more attention to protection of the first responders dealing with victims. They also comprehended the diffusion of the ammonium and spreading of the ammonium cloud.

Communication of meaning among the multiagency ER company:

In this phase of the analysis the aim was to see how and with the aid of which media the understanding of the situation was constructed among the Emergency Response Centre, IC and the first responders. The analysis focused on communication of meaning of the accident situation. A triadic semiotic model was used to understand the communication process. The model assumes communication to take place in practical perception action-cycles in which environmental cues or signs (S) denote objects (O). The effect of a sign is an interpretant (I) i.e. an action, emotion or another form of behaviour that indicates that the relationship between S and the O has been established and understood. This semiotic structure may be used in the analysis of a continuous communication process (semiosis). The analysis is targeted to describing the process that creates understanding and meaning concerning the situation

The analysed activity was divided in several episodes with regard to which we clarified: What was the object of communication and how the object evolved during the episode, i.e. what content COP had during this episode? What signs were central in launching the communicative process? How widely shared the object was? What media were involved in the process?

Results of the analysis of the communication processes in each episode may be summarised as follows:

Observation of the environmental cues (Sign):
- IC works in a highly mediated or indirect way i.e. relies on information from first responder
- First responders (not the IC) often initiate communication i.e. a strong bottom-up pressure of the formation of the COP was observed

Formation of the goals in the situation (Object):
- IC's role is to formulate understanding of the situation (COP)
- Formulation of COP takes time, sometimes IC appears to be behind the sectors
- Driver plays a central role in supporting IC formulating COP
- General operational instructions support interpretation and anticipation of actions
- Complexity of the situation requires connections between sector objectives - coordination is needed - assumes dialogue to enhance COP

Acting in meaningful ways (Interpretant):
- First responders primarily communicate by acting on the environment
- IC continuous communication consists of commanding, informing, asking questions and perceiving
- Interruptions of IC are very frequent; hinders formation of COP
- In a complex situation focus on spatially and temporally local problems; restricted COP
- Team orientation strong, hierarchical relations not emphasized (top down control)

Results concerning the media that COP deals with

Instruments
- Extinction tools also serve in a communicative role (hose, rope)
- Communicative features and use of instruments may be improved
- Augmentation of natural senses has proven useful - aim is to perceive the environment more effectively
- Parallel use of various information tools (books, guidelines, computer, TETRA)

Communication tools

- Role of verbal communication (either over TETRA radio network or direct personal communication) was very important
- Little need was identified for the IC to move around the accident, rather maintains his bases and focuses on comprehending the situation
- Mobile connections (e.g. IP) important during the approach

Representation tools

- COP should be understood as a model to be created
- Dominant representation medium was found to be the human mind
- Traditional white board was the only external medium; it was used in the beginning, not when situation became more complex
- Personal, physical contact, gestures appeared a possible form of externalising COP

Next steps of the human factors analysis

The aim in the future is to integrate better the interview results from all the three countries with the results of analyses of real ER activity. There is also a need to elaborate the COPE concept of COP by the communicational perspective that was proposed in the present report.

The results of the design study reported here also indicate that when formulating user requirements three kinds of requirements should be considered:

- Task requirements i.e. requirements that relate to accomplishing role-determined primary and secondary tasks of first responders in different situations
- Communication process requirements i.e. requirements that relate to ways of communicating and constructing a common understanding of the situation.
- Medium requirements i.e. requirements that focus on all the different but intertwined aspects of the COP medium: the instrumental medium, the communicational medium and the representational medium.

Finally, we may state that maybe the original COPE plan for usage-centred design was too linear. Hence, the COPE project has found necessary to establish several design groups to accomplish the design. Real-life design studies were also added to enable dialogue between engineering design and human factors perspectives in the requirement elicitation and technology mapping.

References

Mäkelä, Markku 2007. Opas vaarallisten aineiden onnettomuustilanteiden pelastustoimintaan (Guide to emergency response in accidents involving hazardous substances). Suomen Pelastusalan keskusjärjestö SPEK. Savilahden kirjapaino.
Lautkaski, Risto ja Teräsmaa, Ilkka 2006. Vaarallisten aineiden torjunta (Fighting hazardous substances). Suomen Pelastusalan keskusjärjestö SPEK. Savion kirjapaino.
Neuvonen, Tapio et al. 2007. P3 käsikirja. Teoria (IC handbook. Theory). Savion kirjapaino.
Carroll, J. M., W. A. Kellogg and M. B. Rosson 1991. The task-artifact cycle. Designing interaction: Psychology at the human-computer interface. J. M. Carrol. Cambridge, England, Cambridge University Press**:** 74-102.
Crandall, B., G. Klein and R.R. Hoffman 2007. Workin Minds. A Practitioner's Guide to Cognitive Task Analysis. London, The MIT Press: 73-90.
Keinonen, T. 2007. Immediate, product and remote design. International Association of Societies of Design and Research, Honkong.
Norros, L. 2004. Acting under Uncertainty. The Core-Task Analysis in Ecological Study of Work. Espoo, VTT, Available also URL: http//www.vtt.fi/inf/pdf/.
Norros, L. and P. S. Savioja, L. 2009. Approach to Integrated System Validation of NPP Control Rooms. Sixth American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies NPIC&HMIT 2009, Knoxville, Tennessee, American Nuclear Society, LaGrange Park, IL, on CDROM.
Nuutinen, M. and L. Norros 2009. Core-Task Analysis in accident investigation - analysis of maritime accidents in piloting situations. Cognition Technology and Work (11): 129-150.
Pesonen, L., H. Koskinen and A. Rydberg 2008. InfoXT - User-centric mobile information management in automated plant production. Nordic Innovation Centre (NICe)**:** p. 99.
Savioja, P. and L. Norros 2008. Systems usability - promoting core-task oriented work practices. Maturing Usability: Quality in Software, Interaction and Value. E. Law, E. T. Hvannaberg, G. Cockton and J. Vanderdonckt. London, Springer**:** 123-143.
Savioja, P., L. Norros and L. Salo 2008. Evaluation of systems usability. European Conference on Cognitive Ergonomics 2008, Funchal, Portugal.
Bödker, S. and P. B. Andersen 2005. Complex mediation. Human Computer Interaction 20: 353-402.
Peirce, C. S. 1998. What is a sign? The essential Peirce. Selected philosophical writings. T. p. e. project. Bloomington and Indianapolis, Indiana University Press. 2: 4-11.
Vygotsky, L. S. 1978. Mind in Society. The Development of Higher Psychological Processes. Cambridge, Mass., Harvard University Press.
TOKEVA-ohjeet Suomen palokuntia vaarallisten aineiden torjuntaa varten (TOKEVA Guides to Finnish firebrigades for fightin hazardous substances). Pelastusopisto.
Clark, H. H., & Brennan, S. E. (1991). Grounding in communication. In L. B. Resnick, J. M. Levine & S. D. Teasley (Eds.), *Perspectives on socially shared cognition*. Washington: D.C.: American Psychological Association.
DII COE Common Operational Picture (COP) Technical Requirements Specification (TRS), Defense Information Systems Agency (DISA), 4Dec 1998
Defense Information Infrastructure Common Operating Environment (DII COE) Home Page, Office of the Defense Information Systems Agency, (http://diicoe.disa.mil/coe/), August, 2000.
Defense Information Infrastructure (DII COE) Technical Working Groups and Advisory Group Page, Office of the Defense Information Systems Agency, http://diicoe.disa.mil/coe/aog_twg/twg/twg_page.html), August, 2000.
Endsley, M. R. (1995a). Situation awareness and the cognitive management of complex systems. *Human Factors Special Issue, 37*(1), 85-104.

Endsley, M. R. (1995b). Toward a theory of situation awareness in dynamic systems. *Human Factors Special Issue, 37*(1), 32-64.

Endsley, M. R., & Bolstad, C. A. (1994). Individual differences in pilot situation awareness. *The International Journal of Aviation Psychology, 4*(3), 241-264.

Endsley, M. R., & Kaber, D. B. (1999). Level of automation effects on performance, situation awareness and workload in a dynamic control task. *Ergonomics, 42*(3), 462-492.

Hutton, R. J. B. (2005). Some Observations on Shared Understanding in Joint Military Operations At CGSC Joint Advanced Warfighting Seminar. Final Report prepared under contract DAAD19-01-C-0065 for US Army Research Laboratory, Human Research and Engineering Directorate Field Element, US Joint Forces Command, Joint Futures Lab, Joint Experimentation Directorate, J9. Dayton, OH: Klein Associates Inc.

Klein, G., Armstrong, A., Woods, D., Gokulachandra, M., & Klein, H. A. (2000). *Cognitive wavelength: The role of common ground in distributed replanning* (Final Report under Contract #F33615-99-P-H562, AFRL-HE-WP-TR-2001-0029). Fairborn, OH: Klein Associates Inc. [also published as DTIC No. ADB282561, http://www.dtic.mil].

Klein, G., Phillips, J. K., Battaglia, D. A., Wiggins, S. L., & Ross, K. G. (2002). *Focus: A model of sensemaking. Interim report - year 1 prepared under contract 1435-01-01-ct-31161 [dept. Of the interior] for the US Army research institute for the behavioral and social sciences, Alexandria, VA* (Interim Report - Year 1 prepared under Contract 1435-01-01-CT-31161 [Dept. of the Interior] for the U.S. Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA). Fairborn, OH: Klein Associates Inc.

Michael D. McNeese, Mark S. Pfaff, Erik S. Connors, Joaquin F. Obieta, Ivanna S. Terrell, and Marc A. Friedenberg (2006). MULTIPLE VANTAGE POINTS OF THE COMMON OPERATIONAL PICTURE: SUPPORTING INTERNATIONAL TEAMWORK. *PROCEEDINGS of the HUMAN FACTORS AND ERGONOMICS SOCIETY 50th ANNUAL MEETING. Santa Monica, CA: HFES.*

Rentsch, J. R., & Hall, R. J. (1994). Members of great teams think alike: A model of the effectiveness and schema similarity among team members. *Advances in interdisciplinary studies of work teams, 1*, 223-261.

Shalin, V. L., Geddes, N. D., Bertram, D., Szczepkowski, M. A., & DuBois, D. (1997). Expertise in dynamic, physical task domains. In P. J. Feltovich, K. M. Ford & R. R. Hoffman (Eds.), *Expertise in context: Human and machine* (pp. 195-217). Menlo Park, CA: AAAI/MIT Press.

Thordsen, M. L., & Klein, G. A. (1989). Cognitive processes of the team mind. Proceedings of the *IEEE international conference on systems, man, and cybernetics*. Cambridge, MA.

Zsambok, C. E., Klein, G., Kyne, M., & Klinger, D. W. (1992a). *How teams excel: A model of advanced team decision making*. Fairborn, OH: Klein Associates Inc.

Zsambok, C. E., Klein, G., Kyne, M. M., & Klinger, D. W. (1992b). *Advanced team decision making: A developmental model* (No. Contract MDA903-90-C-0117 for U.S. Army Research Institute for the Behavioral and Social Sciences). Fairborn, OH: Klein Associates Inc. [also published as DTIC No. 259512, http://www.dtic.mil].