ABSTRACT

**Motivation** – To improve Emergency Response activity by designing technical support to maintain a common operational picture (COP) of the emergency situation.

**Research approach** – A design experiment was conducted to test solutions to support identification of hazardous gases in an accident. A new method was proposed to tackle the known design problem labelled the “task-artefact-cycle” and to identify promisingness of technologies in a future context of use.

**Findings/Design** – The results reveal decision making demands in a fire situation, how they are tackled in the present practice, and what added value the tested new technology might bring.

**Research limitations/Implications** – The study was a first case in which the proposed method was used.

**Originality/Value** – The research proposes a theoretically based new method for analysis of user activity in the design context.

**Take away message** – The “task-artefact cycle” can be tackled by creating conceptually oriented formative methods of activity analysis.

**Keywords**
Activity analysis, design study, emergency response, common operational picture

INTRODUCTION

Emergency Response (ER) is a dynamic multiagency activity characterised by high risks for the safety of the public and the emergency response personnel. One of the key issues in coping with the risks of the emergency situations is that the personnel create a realistic and timely understanding of the situation and identifies adequately the needs for action. In a EU-funded project labelled Common Operational Picture Exploitation (COPE) the attempt is to develop ICT tools and new practices to improve ER activity.

OUT OF THE TASK-ARTEFACT CYCLE

The analyses of activities for eliciting of user requirements in usage-driven design normally focus on present activities. The generic dilemma that the designers and their human factors collaborators face is that tools and activity in which they are used typically change interdependently. When the designed new tools are ready for implementation the activity has changed. The user demands that the tools should support are more or less outdated. This vicious circle was labelled as the task-artefact cycle (Carroll, J.M., Kellogg, W.A. and Rosson, M.B. 1991). To avoid finding ourselves in this trap we attempted to create means that would carry us over the dilemma. The basic means is to distance ourselves from the existing way of accomplishing the task and to try to define a possible new way of doing the job. At least two methodological possibilities are open here.

The first possibility is a theoretical and conceptual distancing. As has recently been shown by Keinonen (2007), the present design practice that he labels “immediate design” is characterised by sensitiveness to the users’ current or expressed future needs, by its context dependency and rather extensive utilisation of layman designers. Immediacy of this design mode does not only refer to time and location but also to causal and value-based immediacy, i.e. the needs of the users are the immediate reasons for design, not e.g. business strategy or technical opportunity in a further sense (p. 10). Another form of design, called “remote design”, again, aims at structural changes in production and usage i.e. at new concepts of operation, focuses on possibilities, and is typically formative i.e. outlines generative solutions. Remote design shapes both expectations and possibilities of the users concerning their activity, and creates possibilities and concepts to further design. Scientific work and innovations are needed to accomplish results, impacts of which become materialised later e.g. when technologies have matured sufficiently to application. The context of implementation of the results of remote design expands beyond the original area of application, and design is motivated by societal and technological policy reasons. The need for this kind of design has been identified recently by companies and designers who express claims for “research like design”.

The present study aimed at representing remote design. But to reach the formative level in design, we found that
it was necessary to start by articulating a generic function of emergency response work called Common Operational Picture (COP) that the project targeted to facilitate. We made effort to understand what the function of COP conceptually is and how it could be supported by new technology and by reorganising work, i.e. by developing a new concept of operations. As the first design experiment, described in this paper, was focused on just one part of the entire COP technology, the notion of COP remained in the side. In the conclusions we shall return to the consequences of neglecting the possibility to reflect COP with the users.

The second methodological line that we found necessary in avoiding the task-artefact cycle was related to the practical methods used in the design, especially task analysis techniques used in the user studies. In this case the leap away from the present towards the future, that a formative design would require, will be made visible also for the users. The idea behind this is that the users are the best experts of the activity for which new tools are designed. Hence, they would, with sufficient support, provide an invaluable input for innovation. The intent was to create an open zone within the present practice that would allow reflection on the restrictions of the present tools and enable innovation of new ones.

As a background we exploited the notion of “zone of proximal development” (ZPD) proposed by L.S. Vygotsky (1978). This concept was invented by Vygotsky in his studies on child development. During the studies he was interested in identifying a child’s potential to learn, instead of merely defining the level of achievement the child has reached so far. The latter was the focus of all methods existing then. His novel idea was to identify what would be the level of achievement in certain cognitive tasks that the child could reach with the aid of an instructor or a more advanced collaborator. The distance between the individually realised level of achievement and that reached together with a collaborator tended to vary among children who manifested the same individual level of achievement. The difference between those two levels of achievement was labelled the zone of proximal development (ZPD) and it describes the next potential level of the child’s development (see also Kaptelinin, V. and Nardi, B.A. 2006).

In our design context we came to the idea of using the ZPD notion as we realised that it is very difficult to test new technologies in a realistic way in a complex and dynamic activity with many uncertainties that – due to safety reasons - requires extremely well rehearsed action. The flow of actions will be disturbed by an introduction of immature technologies. Moreover, it cannot be assumed that the readiness of the actors to use the tested technology would be sufficient to draw relevant conclusions of the added value of these technologies. ZPD i.e. the possible enhancement of the first responder activity, was interpreted to be identifiable as the difference between the task performance of emergency responders who tackle an accident situation as they are trained to do, and the performance that a group of end-users could identify as possible when aided by the tested technologies, and instructed by the designers of these technologies.

Hence, we created two groups of professional actors who worked in parallel in a real situation. In this arrangement the presently existing practice that can be observed in a real situation, serves as a background or reference against which the possibilities of the new technology used by a second group of actors are tested. The potentials of the technologies and the possible changes in activity are reflected on-line, or after the exercise in a debriefing session. The ZPD is made visible by the two groups of actors in a real situation without disturbing the learned ER activity. Within this open zone, subject matter experts, researchers and designers will have a chance to observe the potential of the technologies and their added value to the studied work.

**RESEARCH QUESTIONS**

The present study is a design study. According to Alain Findeli (2001), the challenge of design is to understand from inside the complex relationships and dynamics of the system within which the designed technology is part. We see that researchers participate in this process with the specific role of reflecting on the course of the on-going transformation process. As Gibbons and collaborators have shown (1994), valuable knowledge created in this process is not only the traditional scientific knowledge, Mode 1 knowledge, but also another type of knowledge, Mode 2 knowledge. The latter type of knowledge is created in the practical, not strictly controlled context, it is transdisciplinary and dialogical in character. Among the quality criteria of this type of knowledge, the issue of relevance of knowledge to the different stakeholders plays an important role.

The cited ideas are in accordance with the focus of the present project. The designers, the researchers and, in particular, the end-user partners have emphasized that the key criterion of a successful design is that added value is created to the first responder activity. Hence, by designing the above described exercise, we expected to identify some restructuring of the first responder activity when augmented by the designed technology. We also expect that the technology that supports perception of the hazards of the chemical substance would increase the salience of safety-relevant actions, and would be experienced as promising for future activity.

**NEW METHOD FOR DESIGN STUDY**

**Creation of a realistic situation**

In our design study we created a realistic usage situation and context in which professional actors were involved. While innovative in character we still wanted the study
to provide an experience that may be structured and reflected upon. Hence, conceptual and methodical means were necessary in the design of the study, in data collection and analysis of the results.

The emergency response situation we studied was a realistic exercise situation with 23 Emergency Services College (ESC) 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 an accident with hazardous material. The emergency response activity was viewed from the perspective of the Incident Commander, i.e., the person who is responsible for operations on the site.

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 °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 between a truck, driven by a lone driver, transporting about 20 000 kg of ammonium, and a passenger car, occupied by the driver. Additionally, another passenger car approaching the accident collided with the two vehicles and consequently caught fire. The situation is depicted in Figure 1.

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

**Technology evaluated**

The study focused on possibilities of new means to inform fire fighters and other emergency response personnel of hazardous substances in an accident or fire situation. The technology that was evaluated consisted of ammonia-sensitive sensors that evaluate the concentration of ammonia and also send information of their location on the ground. A wireless sensor network (WSN) delivered the data from the sensors to a laptop where the chemical concentration of each sensor location was made visible in real time. The sensor network consisted of seven sensor nodes including one wireless weather sensor and six field sensor nodes. Only a mild concentration was used.

The one field sensor node nearest to the leak measured the real ammonium level while the remaining five sensors were simulated. However, the receiver was set to simulation mode so that in the experiment, only simulated values of ammonia were used. Additionally, even if some sensors sent information of only simulated chemical concentration to the network, the location of those sensors and the weather conditions around were correctly captured and represented. This meant that the WSN was also used to measure the GPS locations of the nodes and the local weather information.

**The method: Parallel augmented exercise**

As indicated, the idea was to create a realistic test situation in which two forms of emergency response activities run in parallel. The intention was to let the normal practice create a background that would enable testing of the new technologies on-line. The method is here labelled as Parallel Augmented Exercise. This was achieved by letting a first activity, here called “Present Operations” (PO), to take place as comprehensively and undisturbed as possible. In our case the “Present Operations” was the ESC students performing the expected emergency response activity in the situation described above. Parallel to the PO, a second activity was created. It was called the “Augmented Operations” (AO). It involved only two professional fire fighters who adopted here the role of an incident commander. These emergency responders were supported by the designers in order to be able to use the new technology they tested. The AO group was devoted to testing and creating ways of using wireless sensor technologies in the emergency situation so that they could observe the PO group activities.

The AO group planned the implementation of the wireless sensors in the environment (which were deployed into the environment by the help of two first responders from the PO group), exploited the information that the sensors delivered, and considered how this information could be used by an Incident Commander (IC) responsible for such a situation. The AO group did not influence the activity of the IC of the PO group. Instead the AO group was advised to imagine how the information gathered would influence and support the work of the IC.

**DATA COLLECTION**

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

**Present Operations (PO)**

The participants of the Present Operations group took the roles of an incident commander (IC) and the roles of fire fighters. The test involved three fire fighter units (5+1 men each), one ambulance unit (1+1), and one incident commander. The police service was simulated by the instructor, who also played the role of Emergency Response Centre (ERC).
Complete registration of telephone traffic was accomplished. The students utilised the TETRA command communication network. Video recordings were taken with two simultaneous cameras, one recording the IC performance in the command vehicle, and another in the field recording the accident and fire fighters performing their tasks. Debriefing with the PO group, lead by the instructor, was also video recorded.

**Augmented operations (AO)**
The participants of the Augmented Operations group were two commander course students who had experience of professional IC work. Their role in the exercise was “silent IC” as they only observed the performance of PO, without interfering the course of events in any way.

Video recordings were taken from the command vehicle with a mobile camera. During the exercise the two professional fire men also used a book-keeping template, including time, received information, and the actions that the information acquired by the new technology gave rise to. The two members of this group were also interviewed, questions dealing with the applicability and ideas related with the new technology.

**ANALYSIS OF EMERGENCY RESPONSE ACTIVITY**

**Task analysis and modelling the decision making demands**

In order to understand the situation, i.e., what the common operational picture to be supported by the new technology in this specific situation is, and to be able to analyse the proceeding of the accident, task analysis was performed before the actual activity took place. The task analysis was performed in two phases: We created *Functional Situation Model* and also defined the decision making demands.

The functional situation model describes an activity in the studied situation (see Picture 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.

**Picture 1. Functional Situation Model describing accident phases (bold text), main purposes of ER activities (in red) and ER functions during the various phases (boxes in coloured background).**

Decision making demands were identified by Finnish incident commander guidelines. The main decision-making demands are listed below.

- Creation and maintenance of awareness of the situation, most important features to comprehend being:
  - 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 (inner cordon)
  - 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 (outer cordon)
Using the available information e.g. the diffusion model (ESCAPE software) to define the protection zone
- Coping with uncertainties due to wind and the specific features of the terrain
- Decision for ways of protecting population for chemical threat

The outcome of the task analysis was used as a reference in the analysis of the real activities of the PO and AO groups.

**Analysis of real activity during the exercise**

*The design study focused on identification and estimation of the added value of new technologies – information obtained from chemical sensors and weather station, connected by wireless sensor network - in an emergency response in fighting hazardous substances.*

Three viewpoints were taken in the analysis:

**Successfulness of IC decision making**

The criteria used focused on the appropriateness of the emergency response in the exercise and referred to the performance of the PO group, and to the reflections of the AO group concerning the decision making. The criteria were 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.

**Promisingness of the new technology in IC decision making**

Further evaluation criteria concerning the added value of the studied technology were defined. These were referred to as criteria for the “promisingness” (or potential) of the new technology. The idea was 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 were needed to make conclusions about the experiences of the “Augmented operations”.

**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.

**RESULTS: ADDED VALUE OF THE NEW TECHNOLOGY**

**Successfulness of IC decision making**

Firstly it was evaluated how critical decision making demands were met by the PO group. Next, drawn on the observations and interviews of the AO group, such points were raised in which the new technology appeared to have supported decision making. Only such

<table>
<thead>
<tr>
<th>Present Operations/media</th>
<th>Decision-Making Demand</th>
<th>Augmented Operations/media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetra, white board, driver, guide books, ESCAPE, maps, personal contact</td>
<td>Creation and maintenance of situation awareness</td>
<td>Immediate danger conceived</td>
</tr>
<tr>
<td></td>
<td>Focus on immediate danger and operations to stop the leak</td>
<td>Diffusion of the cloud and protection of population conceived</td>
</tr>
<tr>
<td></td>
<td>Diffusion not conceived appropriately</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Three sectors established</td>
<td>Organising response activity in three sectors</td>
</tr>
<tr>
<td></td>
<td>In two sectors insufficiencies to maintain proper actions (burning car, water supply)</td>
<td>Instructed sensor implementation; identified need for re-placement of sensors</td>
</tr>
<tr>
<td></td>
<td>Approach close to target, did not reconsider the distance; Danger zone not clear =&gt; protection of fire fighters (FF) inadequate</td>
<td>Need to increase danger zone was identified</td>
</tr>
<tr>
<td></td>
<td>Definition of the immediate danger zone</td>
<td>Need to establish a clear border identified</td>
</tr>
<tr>
<td></td>
<td>Insufficient anticipation of the spreading of the cloud, insufficient planning of population protection</td>
<td>Adequate protection of FF identified</td>
</tr>
<tr>
<td></td>
<td>Planning of protection zone and protection of population</td>
<td>Realistic picture of the threats</td>
</tr>
<tr>
<td></td>
<td>Heavy telephone traffic, difficulties to monitor all on-going activities, partly reactive responses</td>
<td>Monitoring on-going response activities</td>
</tr>
<tr>
<td></td>
<td>Monitoring on-going response activities</td>
<td>Not involved</td>
</tr>
</tbody>
</table>

Table 1. Comparison of decision making between present (PO) and augmented operations (AO) groups.
demands were specified that the new technology has some impact on. In Table 1, an overview of the benefits of the new technology from the decision making point of view is presented.

Evidently, new technology would have supported in functions that depend on the availability and correctness of information related to chemical substance concentration. If the same information would have been available to the PO group, it is possible that professionals (fire fighters) and civilians (population around) would have received appropriate commands and instructions, respectively, to perform protective actions against the chemical cloud in a comprehensive way.

**Promisingness of the new technology in IC decision making**

Promisingness is evaluated according to Systems Usability evaluation (Pesonen, L., Koskinen, H. and Rydberg, A. 2008; Savioja, P. and Norros, L. 2008; Norros, L. and Savioja, P.S. L. 2009), drawing on the idea that the technology must be evaluated in the activity system context in which it is going to be implemented. The criteria for evaluation are on the three functions that a tool for human activity is used for, namely 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 of the substance to people. This information is important in incidents where a 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 a 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 by using colour coding, which was intuitive to understand. Accordingly, the explicit location of the sensor, as it is put on a map interface, is natural and easy to understand. 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. Only the information of wind direction was not found easy to understand as it was beside the map and the direction presentation could be interpreted in two opposite ways. A better way will have to be designed for wind direction presentation.

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 action 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.

**Constraints on technologies and problems identified**
The design experiment was conducted in poor weather due to constant rain. The connectivity within the wireless sensor network was further put to the test by the landscape as the furthest sensors were behind a hill. Nevertheless, the functionality and reliability of the WSN and sensor technology from a technical point of view proved to be adequate to be used in realistic situations.

Both researchers (the authors) and the AO group members reflected the constraints and problems related to the new technology. From the point of view of emergency operations, it was found that the availability of human resources is restricted so that the placement of sensor should not require too many ER resources. Moreover, the user interface should be simple and intuitive in order to be easy to use in a demanding decision making situation. Both the ways to manipulate the technology and the way to indicate chemical concentration should be effortlessly understandable.

Finally, there should not be uncertainties in the model of chemical cloud concentration. Hence, the overall system should be technically dependable and users should be given proper training so that they understand the limitations of the information given by the predicting technology.

**DISCUSSION: BENEFITS AND RESTRICTIONS OF THE USE OF PARALLEL AUGMENTED EXERCISE**
The use of two partly interdependent groups proved to provide relevant information regarding the usefulness and meaning of the new technology in ER response. Even if the technology was not fully developed, but rather demonstrated the aimed concept, it was possible to use it for evaluating its added value. The existence of a group using the technology in parallel with another group using the conventional technology provided a possibility to compare the value of the new technology, in a realistic situation.

In order to reach the objectives, the exercise must be carefully designed though. In the present study, the parallel group with the new technology was co-located in the same vehicle as the PO group members but the interaction between the groups was not symmetrical.
The AO group heard and saw the same information as the PO group but additionally, the AO group evaluated the efficiency of the actions made by the PO group member without releasing any information to the PO group. On the contrary, PO group members did not have any advantage over the AO group but performed the command tasks as normal. The possibility of having these two types of groups in the same area without disturbing each other requires enough space and additionally the new technology should be mobile enough so that it can be put to the same location. Furthermore, the new technology should be possible to put out of sight of the PO group members so that they do not get any advantage of it in their work.

The value of the use of the two groups depends on the level of professionalism of their members. When the PO group is represented by professionals, it is ascertained that its actions provide a true reference that expresses the present operations in a genuine way. Accordingly, the members of the AO group should be professionals so that they are able to evaluate the added value of the new technology – it requires profound understanding and experience of present operations. Equally importantly, it requires the ability to evaluate new technology without focusing on flaws in the user interface due to the incompleteness of the technology. This is demanding, and was balanced by clarifications made by the researchers.

The main restriction of the two-group design was that, as the AO group did not have actual impact on the accident process, the information of the changes on the work processes did not become fully evident. It is possible that the technology would change the direction of actions to totally new tracks. The test design used is, however, capable of demonstrating at what points and how, during the present process, the new technology would add value to present procedures. As the new technology is currently only in the developing phase, it is not possible to use a more comprehensive setting to evaluate its value. A real change in procedures is a time-consuming matter that requires not only the presentation of new technology but also extensive training that includes the usage of the technology and the new processes where the technology is efficiently exploited.

All in all, the use of two parallel groups, one performing according to present procedures and other evaluating the situation with the support of new technology, proved to be a useful and innovative way of eliciting benefits and restrictions of the new technology. Observations and notes made during the exercise can and should be complemented with interviews and other sources of information related to the domain so that as good a picture of the demands in the field can be formed as possible.

CONCLUSIONS
Exploitation of the parallel augmented exercise method allowed us to identify seeds of restructuring of the first responder activity when augmented by the designed technology. We also observed that, with the aid of this technology, future practices could become more informed of the risks to the emergency response personnel, to the public and to the environment. The users of the new technology even though they did not in practice experience the benefits of the technology, found the technology promising. Hence, we may conclude that, used during the design process, the method supported opening the task-artefact cycle by making the zone of proximal development of the emergency response activity visible.

The study focused on one part of the technology that, as a whole, should support common operational picture (COP) exploitation. In the further development and testing of the COP technology we assume that beyond demonstrating the benefits of the partial applications, it will be essential that the end-users comprehend the information infrastructure that enables continuous online communication among different applications and human actors. The improved possibility of information and communication is expected to be the central added value of the technology, and it may have major impact on the future concept of operations. Testing this perspective of COP technology assumes that in the design of the further exercises, more emphasis is needed on conceptualising the new technology and the concept of operations with the end-users. Such a conceptualisation of the target of learning that provides means for learning was labelled by Vygotsky as double means for learning was labelled by Vygotsky as double conceptualisation of the target of learning that provides stimulus (Vygotsky 1986, Kaptelinin and Nardi 2006). Application of this theoretical tool is expected to strengthen the comprehension of new possibilities and to pave way for actual transformations of practices.

REFERENCES


