The WORKPAD Project Experience: Improving the Disaster Response through Process Management and Geo Collaboration

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ABSTRACT

In complex emergency/disaster scenarios teams from various emergency-response organizations collaborate with each other to achieve a common goal. In these scenarios the use of smart mobile devices and applications can improve the collaboration dynamically. The lack of basic interaction principles can be dangerous as it could increase the level of disaster or can make the efforts ineffective. The paper focuses on the description of the main results of the project WORKPAD finished in December 2009. WORKPAD worked on a two-level architecture to support rescue operators during emergency management. The use of a user-centered design methodology during the entire development cycle has guaranteed that the architecture and the resulting system meet the end-user requirements. The feasibility of its use in real emergencies is also proven by a demonstration showcased in July with real operators. The paper includes the qualitative and quantitative showcase results and mentions some guidelines which can be useful for persons who want to develop emergency-management systems.

Keywords

Mobile Devices, User-Centered Design, Process Management System, Data Integration, Geo-referenced Systems.

INTRODUCTION

Due to the recent increase of safety threats like environmental disasters or terrorist attacks, Crisis Response has become a relevant application field for the development of new information technologies. In this field, team members need to collaborate in order to reach a common goal. The use of mobile devices and applications is valuable for the improvement of collaboration, coordination and communication amongst team(s) to achieve the desired goals. But there are also risks in the usage of mobile applications e.g. decrease of performance. In emergency/disaster scenarios most of the tasks are highly critical and time demanding; for instance, in such scenarios the saving of minutes can result in saving people's lives. The lack of information integration in an emergency scenario could inhibit government agencies and volunteer organizations to successfully communicate and act in a coordinated way. Therefore it is unacceptable to use systems that lack proper interaction principles.

The WORKPAD Project (`www.workpad-project.eu`) achieved to provide an architecture that, intends to improve the collaboration in emergency management by leveraging on the above principles. According to the initial user requirements collection (de Leoni et al., 2007) the Consortium learned that the most suitable architecture is two-level: a first level is deployed on the spot and a second level involves the servers of the different rescue organizations. There are several front-end teams on the field, each composed of several rescue operators. Rescue operators are equipped with PDAs and their work is orchestrated by a Process Management System which is located on the member's PDA. The Process Management System manages the execution of emergency-management processes by orchestrating the human operators with their software applications and some automatic services to access the external data sources and sensors. At the back-end side data sources from several servers are *automatically* integrated and the result is a single virtual data source that front-end devices can query, thus obtaining information aggregated from several sources.

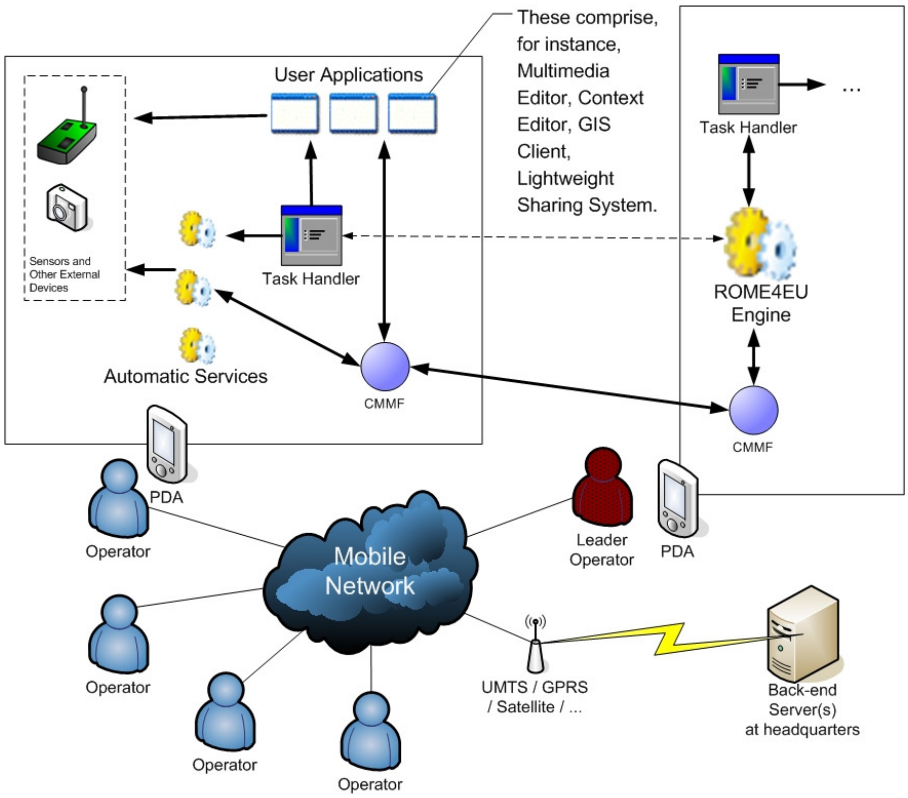


Figure 1. The overall WORKPAD Architecture

The development of WORKPAD followed a methodology focused on user-centered design principles (Dix et al., 2003). This methodology relies on continuous involvement of users during the whole development cycle which guarantees that the final system meets user expectations. The section "Overview of the usability evaluation methodology" will provide detailed information about the different types of user tests performed within the scope of the project.

The feasibility of the WORKPAD system is demonstrated by a drill that the project consortium showcased on 18th June 2009 in the town of Pentidattilo (Calabria, Italy). In particular we simulated the occurrence of an earthquake and asked real users from different rescue organizations to deal with the situation by using WORKPAD. A video that illustrates the successful showcase is available at **`http://www.youtube.com/watch?v=48Hs5Qwg0ho`**. Section "Workpad Showcase" gives more details on a showcase storyboard and illustrates the interaction among the WORKPAD components. Section "Showcase Results and Some Guidelines" summarizes the showcase results, provides information on the user evaluation and mentions some guidelines which were established based on the evaluation results.

The existence of two levels in the architecture and the strong focus on user evaluation is a novelty compared with other relevant research projects in the area of emergency management, such as SHARE (`http://www.share-project.org`), FORMIDABLE, EGERIS (`http://www.egeris.org`) and ORCHESTRA (`http://www.eu-orchestra.org`).

THE WORKPAD ARCHITECTURE

Two classes of users were identified: *Back-end* and *Front-end* users. The identification is based on the Consortium's understanding of how Civil Protection works in Italy and other countries and on the collected user requirements (de Leoni et al., 2007). From an organizational perspective, front-end includes several teams of rescuers that are sent to area in order to manage an emergency, whereas back-end includes the control rooms/headquarters of the diverse organizations that have rescuers involved at front-end. These control rooms provide instructions and information to front-end teams to support their work. Typically, control rooms are provided with servers whose data need to be integrated in order to provide an unified view over the available information. At front end, every team is headed by a "leader operator", who coordinates the intervention of the other team members.

Figure 1 shows the overall WORKPAD architecture. The figure refers to one single (front-end) team with different operators who are coordinated in an emergency. The operators collaborate with the support of PDAs.

Collaboration strictly depends on the possibility that operators and their devices can communicate with each other. Communication is executed on top of mobile networks. Such mobile networks provide gateways to connect to Back-end Servers which are located at head-quarters, where the operators store data and also receive further information for their work. Based on the data of the emergency situation the head-quarter leaders can make new decisions about how to move on with emergency management. Front-end teams are composed of several workers who are equipped with low-profile devices, i.e. PDAs. This fact poses several constraints in the development and deployment of the components as memory is limited in size and CPUs are not very powerful. Reduced screen size raises also new Human-Computer Interaction (HCI) issues, as the amount of information that can be visualized at the same time is not as much as on a laptop.

A Process Management System named ROME4EU is at the heart of the system. It manages the execution of processes. The core component is the Engine which assigns tasks to qualifying members. One of the workers in the team is the team leader. In addition to perform tasks, the leader supervises the work of the others. The engine is installed on the most powerful device which is typically the team leader's device. The engine performs task assignments on the basis of some preconditions over the process status. Preconditions can range from the completion of tasks to variables which have a value in a certain interval and to the availability of certain members skilled with specific capabilities (e.g., equipped with cameras or specific external sensors). When a certain task has been assigned to a certain operator, the Engine connects to the client running on the device named Task Handler. The Task Handler is informed about each assignment made to the respective operator. The communication between the Engine and the Task Handler relies on a Web service middleware. Each message is exchanged by a one-way invocation of a Web service end point. Once the Task Handler receives notification of a certain task assignment to respective users, it displays the name of the task together with relevant information. At any time users can decide to start a task by accepting the offer. In fact, task handlers do not execute process tasks: tasks are executed with the support of external applications. The Task Handler only takes care of mediating the interaction between users and the ROME4EU Engine and starts the applications that support users in the execution of tasks. For instance, the task "Build a medical tent" can be supported by the GIS-based application which shows the area, the terrain conditions and differences in altitude, as well as buildings and other objects of an area. In this, the best location is identified where to build a tent. The fact that the ROME4EU's Task Handlers and the engine are fully operational on PDAs is an important novelty with respect to the current state of the art of PMSs and, more in general, CSCW. As a matter of fact, we motivate in (Battista et al., 2009) that almost all of the other Process Management Systems require the server engine to be running on a laptop/desktop.

Some tasks may be automatic, i.e., no human intervention is required to carry them out. This kind of tasks is executed automatically by some special services running on a certain device. For instance, there exist some automatic services that retrieve environmental data from sensors and store them in the so-called Context Monitoring and Management System (CMMF). There are different kinds of sensors, such as the ones retrieving environmental data (e.g., humidity, temperature, precipitation) or others obtaining the state of devices (e.g., the battery level, the GPS position). CMMF is a P2P System for sharing information among PDAs (Juszczyk et al., 2009). The PDA on which the ROME4EU engine is installed is able to retrieve such environmental data from sensors installed on board of every team PDA. Almost all modern PDAs are equipped with GPS hardware and, hence, it is feasible to assume that every PDA is able to retrieve its own position. The information harvested by sensors is useful to monitor possible changes in the environment; monitoring is very important, since unexpected events can prevent processes from being completed successfully, if they are not managed. The event management can cause actions to be enacted, which can range from a reassignment of certain tasks to a full restructuring of the process (and, hence, new tasks may be needed).

In the WORKPAD project we have developed the following applications to support the execution of emergency management tasks:

- The *Context Editor* component lets users enter additional contextual information that the sensors couldn't capture automatically. Context Editor stores all inserted data in the CMMF and retrieves them for the same component.
- The *Multimedia Editor* allows users to take and modify pictures of an area.
- The *GIS Client* (Bortenschlager et al., 2008) allows users to make an overview of the area and retrieve relevant information of the objects and buildings present in the area. The position of every team member is visualized to get a quick insight into the area where members are operating. Information of the relevant objects and buildings can also be updated. All the information is stored in a Back-End GIS Server and cached locally to the front-end team for quicker retrieval.

- The *Lightweight Sharing System* enables to share pictures, questionnaires and other files among all operators. In this way, every operator has the same knowledge of the situation s/he is facing.

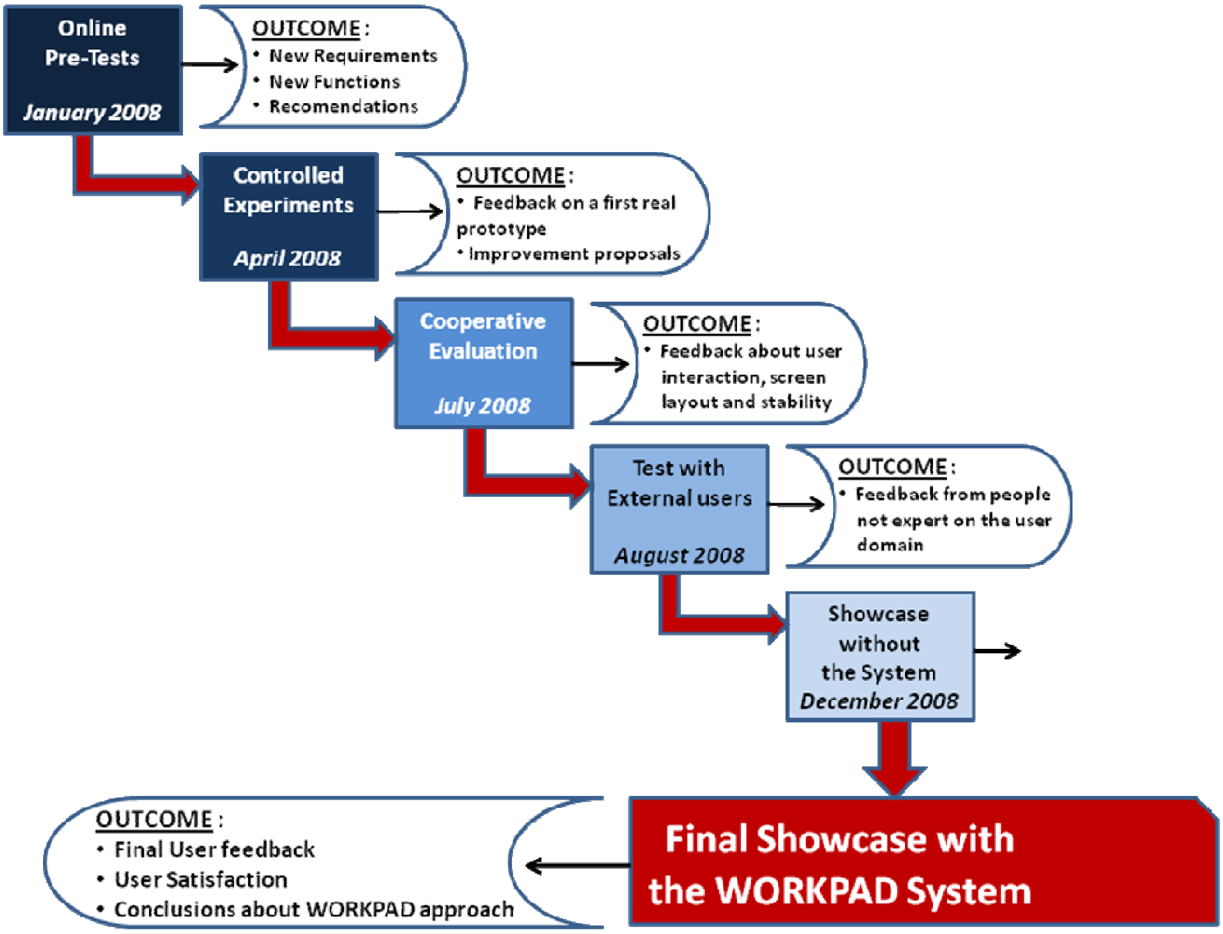


Figure 2. Usability evaluation Methodology in WORKPAD

The WORKPAD Front-end architecture is completely independent of the specific mobile-network technology e.g., it can be deployed on MANETs, or Mesh Networks but it works also with High Speed Downlink Packet Access (HSDPA) or Universal Mobile Telecommunications System (UMTS), even though this technology would delay the situation management due to the low bandwidth. For the showcase with the WORKPAD system in June 2009 we have deployed a Wireless Mesh Network (Wang et al., 2008) (WMN). A WMN is characterized by a backbone composed of several *Mesh Routers* that are connected with each other by multi-hop router paths. Each device connects to one of the mesh routers and can communicate with any other device that is connected to any of the routers. It is unfeasible to suppose mesh routers to be already deployed. Therefore mesh routers should be taken to the emergency area by the operators and power supply should be provided, as well. The realistic solution is to equip civil protection jeeps with routers in order to have the necessary power supply. During the demo, rescue operators reached the area by jeeps equipped with such mesh routers, and they parked them in a way that the entire area is covered. Rescue operators reach the area by the fully-equipped jeeps. They park them in the area in a way that routers can cover the entire area required. Alternatively some of the rescue workers can be equipped with special bags that include a Mesh Router and a small power generator .

WORKPAD front-end networks are connected to specific back-end systems (Vetere et al, 2009), which include a Web services platform to allow data exchange and integration. This platform is designed as a P2P network, in which each system (peer) can act as data provider, consumer and integrator. By plugging into WORKPAD's back-end network, a back-office system works as a WORKPAD back-end peer. This peer exports its ontology (i.e., a schema reflecting its conceptual model) which is mapped on a sort of global ontology. In this way peer data sets are integrated and exposed a single (virtual) data source that can be queried. During the showcase we have simulated several peers that accomplish the query "How many people were roughly located in building X?" We integrated data from the mobile-phone companies together with registry offices.

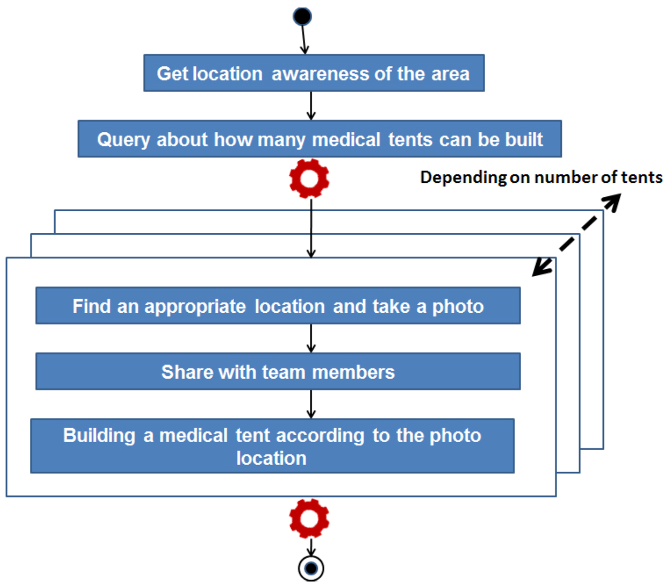


Figure 3. The process describing the Storyboard : "Establishing a medical point"

OVERVIEW OF THE USABILITY EVALUATION METHODOLOGY

The whole WORKPAD system results from applying a methodology that specializes the User-Centered software development process described in ISO Standard 13407. According to the ISO, users have been actively involved throughout the whole software development process, thus ensuring a user-driven development of the system. The results of the user tests were evaluated using qualitative evaluation methods. The evaluation results include improvement recommendations which the developers took into account and meliorated the system. Tests allowed learning the correct requires, thus obtaining a system that, from the one side, improves the task performance (efficiency), and, from the other side, ensures an higher level of usability. Figure 2 gives an overview of the usability evaluation methodology used in WORKPAD. Each evaluation step enabled an improvement of the prototype. We started with paper prototypes and performed the final evaluation of the WORKPAD system in the Pentidattilo drill in June 2009. In the following we list and explain the testing steps accomplished.

- **Online Pre-tests.** The first tests were conducted with online mock-ups. Users were asked to analyze animated images of how the system was envisioned. Then they had to answer a questionnaire on user satisfaction of the different components (i.e., task management, map overview, connection establishment, multimedia and context editor, file sharing).13 users (8 male and 6 female) from Calabria region, 3 of age 46-60 and 10 of age 31-45, with different experience with PDA's participated in the test.
- **Controlled experiments.** After the development of a first software prototype, we conducted experiments on the different WORKPAD components in a laboratory under controlled conditions. These tests intended to observe users when usaging the system and wanted to discover open issues and areas of improvement. Special focus was given to the communication and the integration of the different components: users should feel the impression to work with a single system rather than with different components.
- **Cooperative evaluation.** This method is rooted in the notion that users typically prefer to get to know a system by using it rather than for example study a manual. Initially consortium members explained to the users the purpose of the WORKPAD system and the evaluation. Then users were asked to interact with the system in order to complete a specific task. Evaluators guided the users through the test and continuously interacted with them in order to gather information on user satisfaction. These tests were recorded by video cameras in order for us to analyze the level of the usability of the system off-line and look for recurrent usage patterns that possibly could be speeded up.
- **Test with external users.** After the performance of the user test with expert users, the Consortium accomplished another usability test with people unfamiliar with the emergency topic in order to gain a different perspective on the usability issues.

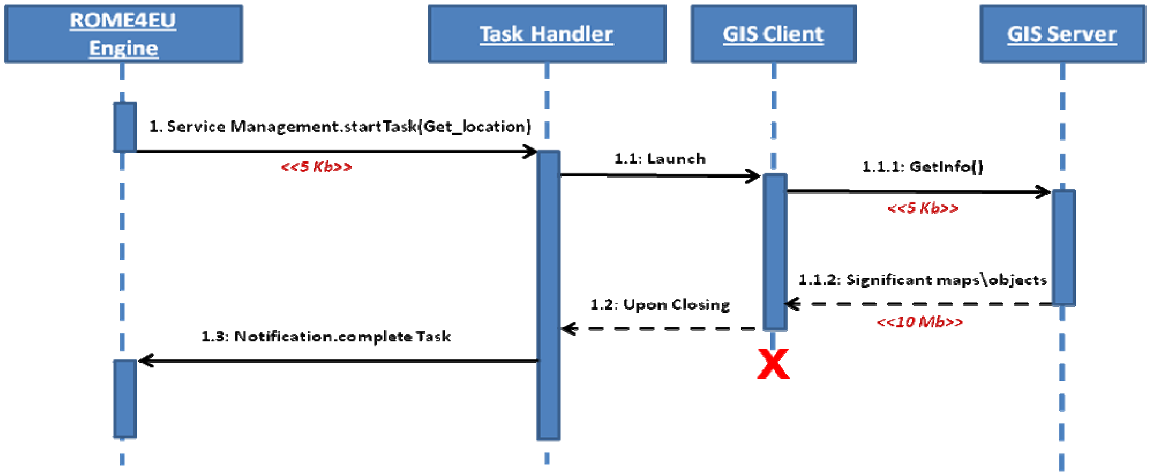


Figure 4. The interaction diagram of the WORKPAD components to enable the execution of task "*Get Location awareness of the area*"

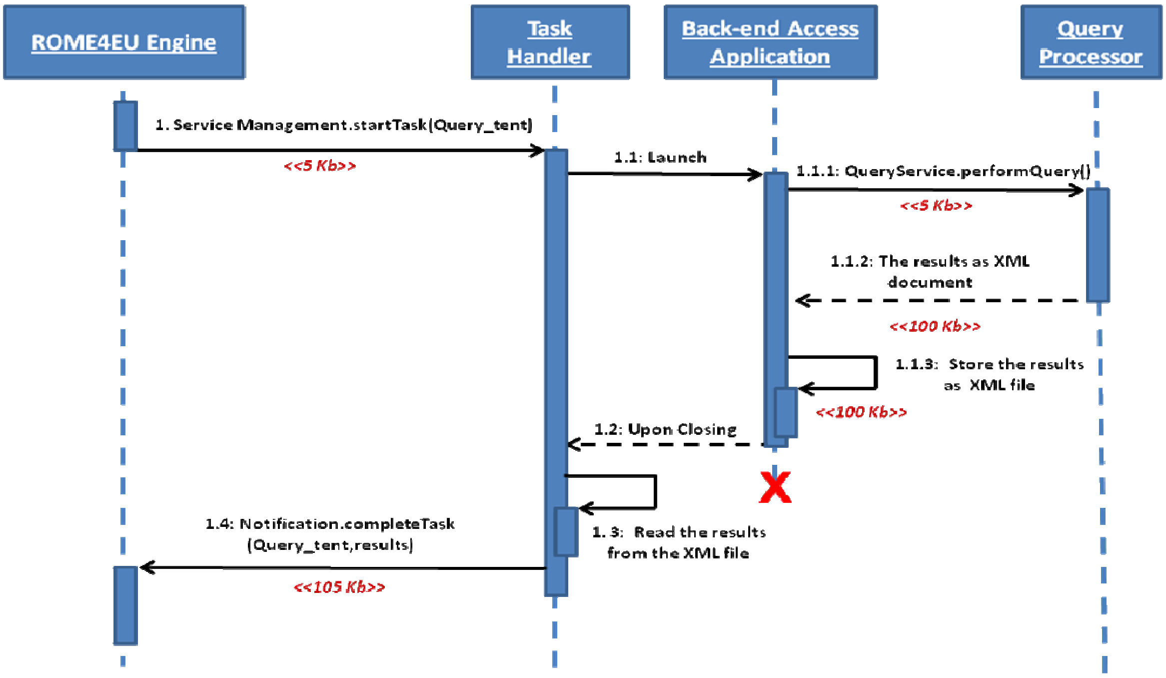
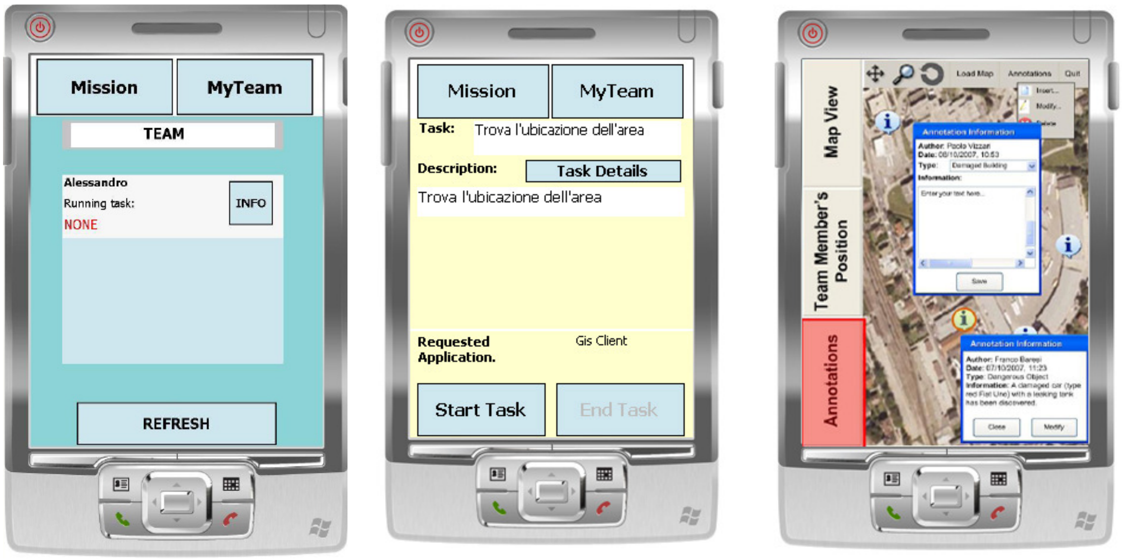


Figure 5. The interaction diagram of the WORKPAD components to enable the execution of task "*Query about how many medical tents can be built*"

- **Showcases.** Term "Showcase" stands for the set-up of a concrete and realistic scenario deploying the system with the purpose of testing the feasibility, effectiveness and efficiency of a system. In WORKPAD, the system was showcased on 18th June 2009 by simulating an earthquake in a certain site with the involvement of real emergency operators. In December 2008 big celebrations were carried out in the same zone of our showcase in order to commemorate a real earthquake that devastated the cities of Messina (Sicily) and Reggio Calabria (Calabria) in Italy in 1998. It caused the death of more than 100.000 people. During celebrations simulations of rescue operations were executed in order to show how real emergencies are nowadays executed (without the WORKPAD's system). In particular we focused our attention on two of the showcased. The first one concerned "building some medicals tents" to provide health support to injured people. The second one dealt with "saving people entrapped in buildings" such as their own houses or offices. According to the experiences earned during their execution in December, we defined two accordant storyboards for the WORKPAD showcase in June.



a) The outlook of the team members and their state.

b) The Task Handler after the assignment of a task to the user

c) The Client of Geographic Information System with some annotation

Figure 6. Screenshots of some WORKPAD tools

THE WORKPAD SHOWCASE

The whole WORKPAD system was completely deployed in a realistic setting in accordance with the architecture previously described. And it was tested during a simulation of an earthquake that was supposed to occur in the small village of Pentidattilo (Reggio Calabria, Italy) on 18th June 2009. As previously said, two storyboards were executed, but the lack of space does not allow us to give details on both. We focus on the storyboard “Build medical tents in order aid injured people”.

Figure 3 depicts the structure of the process for this intent. In the first task emergency teams have to become aware of the area where tents need to be built. “Query about how many medical tents can be built” is an automatic task that is executed by an automatic service that connects to the Back-End and queries for obtaining the number of medical tents required. This query is evaluated by integrating data about the number of injured people and data about the maximum number of tents that are available in certain storage areas. At this stage the process splits in many branches that have the same structure. Each branch concerns one of tents that need to be built up as from the query result. Once initiated these branches are independent of each other and work on local variables, which are synchronized when the branches join again. Every branch comprises the tasks *(i)* to find an appropriate location for a tent and take a photo of it; *(ii)* to share pictures with the other members; *(iii)* to build the medical tents in the locations shown in the pictures shared at point *(ii)*.

Task *(i)* is carried out with the support of the Multimedia Editor, whilst task *(ii)* is supported by the Lightweight Sharing System. Task *(iii)* is slightly different, as most of the work required is not executed by the WORKPAD system: the rescuer uses the Multimedia Editor to watch the photo of the location of interest and then moves there where she builds manually the tent.

During the showcase, we aimed to gain feedback from people with diverse cultural background. In this way, we could improve the effectiveness and efficiency by leveraging on comments from a wider range of users, thus obtaining a final system that mediate different needs. Therefore, the showcase involved rescuers from several organizations that are typically involved in emergency management. In particular, the following organizations were involved: Fire Brigades (in Italian: *Corpo Nazionale dei Vigili del Fuoco – VVFF*), the National Body for Alpine and Speleological Aid (*Corpo Nazionale Soccorso Alpino e Speleologico – CNSAS*), Service of Urgency and Medical Emergency (*Servizio di Urgenza ed Emergenza Medica - SUEM*), Italian Red Cross (*Croce Rossa Italiana – CRI*) as well as two voluntary organizations, i.e. *Europa Unita* and *Confraternita Misericordia*.

The next section provides a summary of the showcase’s results and the user eventuation. This section concludes describing the messages that are exchanged between the WORKPAD’s component to execute certain tasks (such as method invocations, files sent/received, etc.). Figures 4 and 5 show two Sequence Diagrams: arrows are annotated with the size of messages in order to get an insight into the amount of data to be exchanged. The

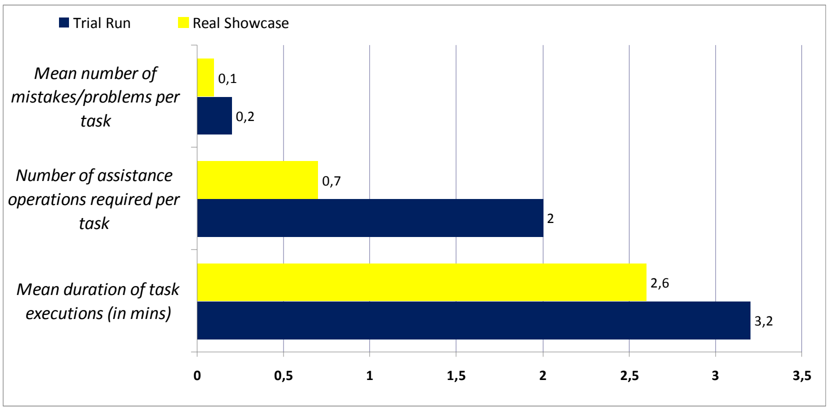


Figure 7. Summary of Task Execution Form Results

purpose is to demonstrate that we successfully achieved the goal of keeping the exchanged data size relatively low and take the slowness of the available communication links into account.

As figures show, the interaction always starts from the ROME4EU engine that assigns tasks to appropriate workers/services. The worker is informed of the task s/he is assigned to through the Task Handler (TH) installed on his/her device, which displays the task name and other information relevant for its execution (Figure 6.b shows the way these data are displayed on the GUI of Task Handler). When workers/services complete the execution of a certain task, Task Handler informs the Engine about the event. The basic size of such messages is quite small, around 5 Kilobytes. Of course the message size may grow depending on the size of the input/output data enclosed in the messages. It is also worthy highlighting that at any time the team leader can overview the status of the other team members in terms of tasks assigned, running, completed. Figure 4 shows the interaction diagram to carry out task "Get Location awareness of the area". This task involves four components: the ROME4EU engine, TH, GIS Client and GIS Server. The interaction diagram is depicted in Figure 4. The GIS Client is the support application for the task execution. The GIS Server is used by GIS Client to retrieve the map of the area. When this task is ready for assignment, ROME4EU chooses the member that guarantees the best performance. Afterwards, his/her Task Handler displays the information of the assignment so as to inform it. When the worker is ready, she/he clicks on the *Start* button. This task is associated to the GIS Client and, hence, after clicking on the button, such an application is launched. GIS Client needs to show some area maps, which are stored in some GIS Server at back-end. Therefore, GIS Client connects to that server, thus retrieving the ortho-photos requested. Figure 6.c shows how GIS Client looks like, once the map is obtained. When the GIS Client application is closed, the task is considered as completed and, hence, the engine gets a notification about the completion, thus enabling other tasks to be assigned.

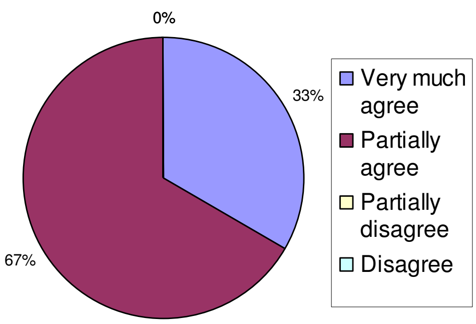
Figure 5 depicts the interaction diagram for task "Query about how many medical tents can be built". This task involves four components: the ROME4EU engine, TH, Query processor and an ad-hoc service that queries the back-end for the right number of tents that need to be built up. This information involves an integration of data from different sources, such as to know the number of tents available in a certain storage area or the number of people available expert for building up the tents, the number of power generators available, etc. The description of the remaining interaction follows the same pattern as task "*Get Location awareness of the area*".

SHOWCASE RESULTS AND SOME GUIDELINES

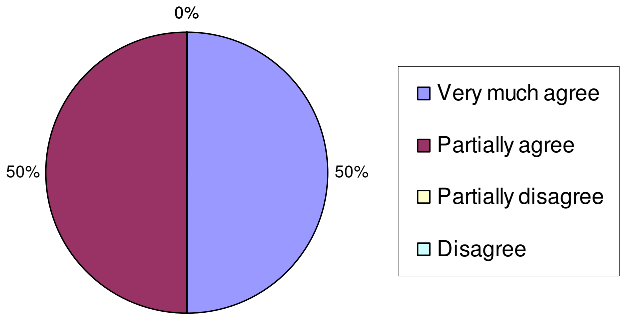
This section describes the results of the showcase. During the showcase we took care of the analysis how frequently users required assistance from consortium members during the execution of showcase tasks with the WORKPAD system. Further on we focused on the number of tasks which were correctly or wrongly carried out and measured the system robustness. Conclusions were drawn on possible problems that users encountered during system usage and on efficiency of such a kind of system for emergency management.

Each of the two storyboards was executed twice. In the first "trial" execution people from the WORKPAD consortium were side by side with the rescue operators and explained them how to use the system to execute the tasks of each storyboard. Afterwards users moved to Pentidattilo which was simulated to be affected by an earthquake and took part in a second "real" showcase. Consortium members accompanied the emergency operators and filled in the task execution forms from which the indicators effectiveness, and efficiency were derived.

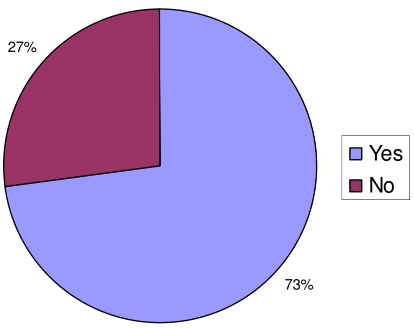
Figure 7 shows the results measured for such indicators. The first conclusion that can be drawn is that the execution of storyboard tasks was longer in the "trial" run than in the real showcase. From this we conclude that the users learned the WORKPAD system very quickly so as to be able to gain benefits just after one run. This



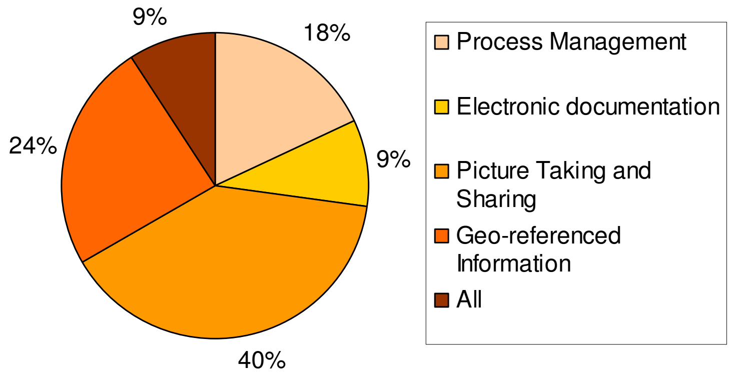
a) Is the WORKPAD system intuitive and easy to use?



b) The system efficiently supports users during their execution of emergency-management activities.



c) Does the WORKPAD system improve emergency management?



d) Which are the aspects that are more useful?

Figure 8. Pie charts of some results of the user evaluation of the WORKPAD system

high level of usability is resulted from applying a user-centered design approach throughout the whole system design and engineering process. The ease of use of the WORKPAD system is also confirmed by the other indicators. The "Number of assistance operations required per tasks" dropped from 2.0 in the trial to 0.7 in the showcase, and "Mean duration of task executions", which decreased on average by 0.6 after only one execution.

After each storyboard execution 12 users were interviewed with the goal to get information on user satisfaction and also to collect proposals for further improvement of WORKPAD. Firstly we made clear to the users that WORKPAD is still a research prototype which can cause some problems in the usage of the system. For half of the test users it was the first time that they used a PDA. This aspect is particularly significant with regard to the good performance results measured during the drill. User feedback is summarized in Figure 8. The first question was whether they regard the system as intuitive and easy to use: four users fully and eight partially agreed (see Figure 8.a). Some users added that they had problems with the visibility on the screen in the blazing sun. The problem of the sunbeams on the PDA's screen seems to be a critical issue; we already discovered the problem during some previous usability tests and tried to improve the screen visibility in these conditions. But it seems that PDA screens are built using technologies that naturally do not address well the direct sunbeams on the it. Other mentioned issues concerned the slowness of the system, but we are sure that further improvements of the WORKPAD system would solve the problem through new technological solutions. As depicted in Figure 8.c, two third of the users repute WORKPAD can really improve the rescue operations. In particular, Picture Taking and Sharing, Geo-referenced Information and Process Management were the topics that mostly impressed the users (see Figure 8.d).

In the light of results obtained during the showcase in term of users' satisfaction and of improvement of the efficiency and effectiveness in emergency management, we are able to mention a few guidelines. These should be taken into account when an emergency management system is being developed:

1. Process Management Systems are useful during emergency management to improve the effectiveness (see also Hagebölling et al., 2009) and the process is a metaphor that is well understood by end users.
2. Task Handler and other client applications should be developed for the usage in extreme conditions and under sunbeams. The use of high-contrasting color should be considered (such as black on white, yellow on

blue). This was also claimed in (Agostini et al, 1996) for CRT monitor displays but the direct applicability of the same guidelines to PDAs does not follow as a consequence. In addition, the GUI widgets should be sized in the way that stylus pens can be avoided (e.g., buttons should be rather big).

3. As also claimed in (Kellerer et al., 2005), Geo-referenced Information Systems are necessary to allow users to gain insight on the current situation. Indeed, they can be combined with ROME4EU in order to enable and improve the collaboration among team members. For instance, geographic information can be used to support ROME4EU to decide whom a certain task should be assigned to (e.g., by leveraging on locations where users are and where tasks need to be executed).

4. As far as implementing applications for Windows-Mobile PDAs, the use of Java should be prevented, as the run-time environment (i.e. the Java Virtual Machine) requires a big amount of memory (roughly 10 Mb) and Java applications access inefficiently to some hardware components (e.g., the GPS sensors) or some configurations of the operating system.

5. Data exchange and integration of various back-end systems located at different head-quarters cannot rely on a hierarchical infrastructure. Different systems cannot rely on a common data schema ("global view") or a repository shared among all systems of all organizations; organizations would not trust such external entities. As in WORKPAD, different organizations need to keep using their (legacy) systems with private schemas, while, at same time, contributing to the global knowledge in a flexible and dynamic way. Moreover, due to rigid privacy policies, organizations need to control what parts of data they want to disclose, map and integrate in the global knowledge, thus making them available for the rescue operations. This vision is complaint (Lenzerini, 2002), and if the Lenzerini's work concerns static scenarios with less time-constrained. We extend here this guideline also to mobile scenarios, including emergency management.

In conclusion, the WORKPAD project has released a novel system, whose novelties lay in the interplay of process management and geo-awareness as basic tools for improving collaboration. This, to the best of authors' knowledge, is one of the few research projects effectively releasing an industrial mock-up, i.e., a running system which with a few efforts can be effectively marketed and made available to emergency operators. The authors are currently involved in an effort aiming at deploying the system in Calabria.

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