THE SAVE ME PROJECT REAL-TIME DISASTER MITIGATION AND EVACUATION MANAGEMENT SYSTEM

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Abstract

Even though safety systems are present in every transportation hub, there are still crucial outstanding issues to be addressed and resolved. Public infrastructures such as tunnels and metro stations are paradigms, where travellers are frequently jammed at the exits, even under normal evacuation. Existing safety systems fail to guide effectively the most vulnerable travellers and to take into consideration the mobility impairment of each individual. In this context, current work, within SAVE ME project, proposes a robust evacuation mechanism from disaster areas in public transport terminals and infrastructures, which is incorporated in our Decision Support System (DSS). The DSS provides groupwised and personalized optimal routes to the exits, taking into consideration the personal preferences and capabilities of the travellers, along with guidelines to the rescue teams, given that rescuers must be sent to prioritized targets with trapped travellers. Furthermore, an innovative contribution of this work is the service personalization platform that was implemented in order to ensure the personalized communication of each traveller with the DSS. Service personalization is based on an intelligent agent framework. The paper provides a thorough analysis of existing evacuation models and mechanisms, presents the DSS architecture, its embedded algorithms, and the service personalization platform. Finally it discusses its performance based on the two SAVE ME project pilot trials in Colle Capretto tunnel in Umbria, Italy and in Monument metro station in Newcastle, UK.

1 Introduction

Many areas in the world have been and are possible to be affected by severe physical disasters, like earthquake, tsunamis, and hurricanes, whereas fire and floods usually occur as immediate results of these incidents. These disasters have obvious impacts to transport operations and means. In addition to the above, a great menace of our time is terrorism. Transportation means, hubs and stations are targets of terrorist attacks, due to the easy access and escape for the terrorists and the fact that crowds in contained environments are vulnerable to conventional explosives and unconventional weapons. During emergencies, there is a number of groups of people for which special emergency planning is needed. The common characteristic of these groups that raises their specific needs is most of the times a type of mobility impairment. Elderly, children, injured and wheelchair users are some of these groups. Moreover, urban disasters over the last decade have shown that even in the most developed economies, catastrophic events routinely overwhelm communications grids. Communication failures in New York City on September 11 contributed to the loss of at least 300 fire-fighters. Another important tool for rescuers is their proper guidance to the people needing help. This effectively eliminates the need for rescue crews to both find and authenticate the isolated person and greatly reduces the risk to rescue crews.

In this context, **S**ystem and **A**ctions for **VE**hicles and transportation hubs to support Disaster **M**itigation and **E**vacuation (SAVE ME) (2009) [15] is an EU Collaborative Project (Small or medium focused research project), where a selection of new types of evacuation models are combined with state-of-the-art sensorial and software agent technologies in order to enhance security in a wide spectrum of transportation hubs.

Current work aims to propose an evacuation model based mainly on graph theory with flow analysis. Apart from simple shortest path computations for personalized evacuation guidance, a contraflow configuration algorithm for re-optimization purposes was designed and implemented. Concerning groupwised evacuation, it was decided to apply the Capacity Constraint Route Planner (CCRP) algorithm. The DSS receives real-time data from the localization module and then sends these data to the crowd and the environmental simulation modules that are responsible for computing the new network situation that is based on the hazard propagation mode. Finally, the DSS provides guidance to the rescue teams by using approximate Deadline-TSP computations.

The paper is organised as follows: Section 2 discusses state-of-the-art on the existing evacuation systems, while Section 3 provides an overview of the DSS architecture, and performs a thorough analysis of the evacuation and rescue plan algorithms and models, along with the service personalization platform embedded into the DSS. Section 4 discusses the performance of the DSS in a set of lab experiments and the real scenario project pilot trials. Finally Section 5 proposes future directions and concludes the paper.

2 Existing Evacuation Systems

Going through related literature, one may identify several approaches that perform evacuation modelling. A majority of these approaches makes use of systems known as Decision Support Systems (DSS). A DSS is a software entity that consists of many parts, which may concern different functionalities. There exist different kinds of evacuation models that are the core of almost every evacuation management system. On the one hand, *microscopic* models emphasize the individual movement and reaction of evacuees. They consider movement of travellers through a network, where the individuals have their own characteristics and respond to the presence of other travellers and to traffic control devices [2]. On the other hand, *macroscopic* models are mainly used to produce good lower bounds for the evacuation time and do not consider any personal behaviour during emergency situations such as the physical abilities of the evacuees [6]. The following paragraphs outline several evacuation management decision support tools and their utilized evacuation models.

- **Oak Ridge Evacuation Modelling System (OREMS).** It has the ability to account for driver behaviour and weather conditions, but it can only assign passenger cars, since it does not perform modal split [3]. OREMS can be used for identifying traffic bottlenecks, and for the evaluation of traffic management strategies [11].
- **Post, Buckley, Schuh and Jernigan (PBS&J) Model.** Its main function is to monitor major congested traffic areas during evacuations for hurricane type events [16].
- **Personal Computer based Dynamic Network Evacuation (PCDYNEV).** It is a macroscopic model which consists of two main parts: integrated TRaffic Assignment and Distribution model (TRAD), and Interactive Dynamic Evacuation (IDYNEV). TRAD is used for the distribution of trips between the zones and their assignment to different links, and utilizes user equilibrium assignment algorithm [5].
- **Network Simulation Model (NETSIM).** It represents a stochastic microscopic traffic simulation model [10]. NETSIM has the ability to model both personal vehicles and buses on congested traffic networks, where the demand is processed and analyzed at each simulation step. However, it can not handle large regional networks, and it does not perform dynamic traffic assignment.
- **EXITUS.** This system [9] is a total new one (2012) and also unique because it considers individuals with disabilities explicitly in terms of physical and psychological attributes.

3 DSS Architecture & Implementation

The DSS implemented in this work, aims to calculate optimal or near optimal routes for every requested evacuation and rescue operation demand by checking for conflicts regarding this route with the appropriate algorithms included in the Personalized Evacuation Module (PEM), the Groupwise Evacuation Module (GEM), and the Rescue Team Planning Module (RTPM), prioritized in the order mentioned above.

Taking into account results taken from the Environmental Simulation Module (ESM), the Crowd Simulation Module (CSM) and the Edge/Arc Affection Module (EAM), the calculation of optimum routes is done by eliminating the combination of them. The combined costs, which are eliminated, are the results of the combination of the environmental, crowd-behavioural and disability (e.g. mobility impairment) related costs. The inputs to the system include the infrastructure network (i.e. a building) and the population distribution with data taken from the Localization Module (LM) in real-time. The calculated routes are then submitted to the Operator Support Module (OpS), which, having a complete view of the network situation, the ongoing and the scheduled routes, it accepts it or rejects it. Moreover, the DSS will calculate alternative routes by using the Replanning Module (RM) in these cases:

- New evacuation plan requested from the OpS.
- The proposed evacuation routes contain segments that have become inaccessible.
- The network situation has changed dramatically during the evacuation cause of a new hazard or the spreading of an existing one.
- There has been a critical change of the evacuees' number.

The above processes continue until the OpS finally allows the application of the proposed evacuation routes. Thus, as it was described above, the DSS considers every evacuation/rescue operation procedure individually. In order to achieve its goal, it combines different types of data in order to achieve high flexibility and adaptation to different kinds of routing problems. Figure 1 illustrates the general view of the DSS modules and of the peripheral ones.

The principal reliability requirements of the DSS, which are fully addressed by the DSS implementation, can be summarized as following:

- The Decision Support System will never select hazardous routes (0% of the time).
- The DSS will provide the initial routing computed at most in 15 seconds after the hazard is identified by the WSN network.
- Alternative routes also identified at most 15 seconds after input informing about hazards in the primary routes comes from the WSN.

In emergency situations, it could be the case the communication might break down partially or completely. The fault-tolerance of the Decision Support System as well as the whole system is ensured and guaranteed via the telecommunications module. The infrastructure behind this module is based on an ad-hoc wireless network with high power autonomy and high power transmission able to restore the required communications in case of disaster events. The fault tolerant communication architecture of the project has been designed following the principles of replication, redundancy and diversity. Moreover, the integration and testing of this infrastructure to the SAVE pilot sites indicated that following these principle fault-tolerant characteristics full communication availability can be achieved, even if several nodes of the Communication Infrastructure were out of order (due to redundancy principle adopted). Finally, the agent-based framework as well as the communication of the Decision Support system with other system components supports the automatic reconfiguration of network in case of periodical communication network loss.

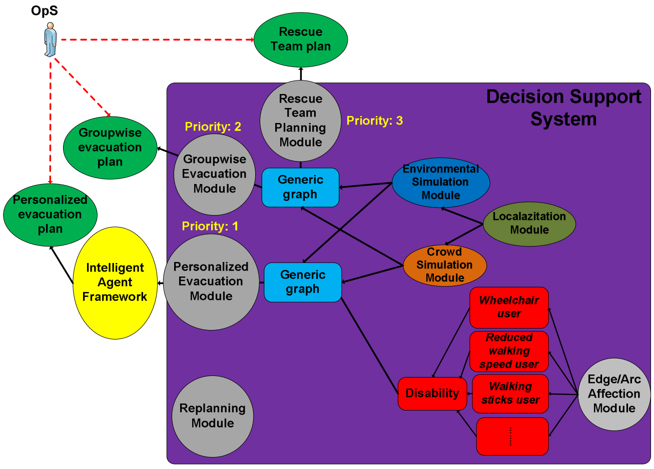

Figure 1: DSS overall architecture

3.1 Intelligent Agent Framework

As can be seen in Figure 1, the intelligent agent framework displayed in yellow represents the service personalization platform of the DSS. The service personalization platform contains a set of agents that enable communication between the DSS and the travellers' mobile phone applications. Appropriate agent roles and behaviours are defined within SAVE ME agent platform, targeting the provision of personalized services to end users. In brief, it can be noted that the DSS system outputs information that considers the personal needs of all travellers. This information is filtered through proper agent behaviours, and as a result, each end user client's application interface is ultimately provided with content tailored to the needs, capabilities and preferences of each respective case.

Figure 2 illustrates the overall telecommunication architecture of the DSS. The multi-agent system is presented above in yellow colour. It should be mentioned that TPAs are mobile agents operating in the mobile phones of the travellers, and were implemented for android and symbian (J2ME) phones.

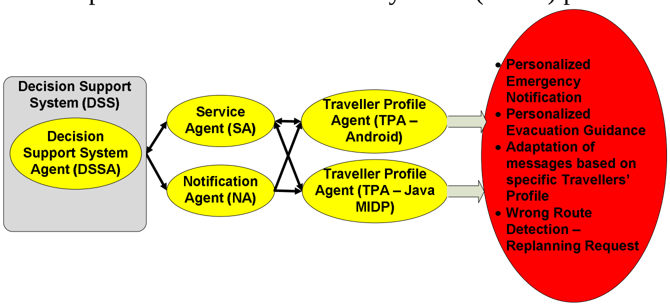

Figure 2: Intelligent Agent Framework

The agent roles that were implemented are described below:

Decision Support System Agent (DSSA):

- Provides interconnection between the DSS and the intelligent agent platform

Notification Agent & Service Agent (NA & SA):

- Transmit travellers messages to the DSS
- Filter the receivers of each personalised DSS message according to the current location and special needs and preferences of the TPAs.
- Keep a record of the connected TPAs along with their location and their profile data (mobility impairment information, preferences, age)

Traveller Profile Agents (TPAs):

- Personalized display of emergency notification messages
- Personalized display of current location and evacuation plan
- Adaptation of messages according to specific traveller's profile
- Wrong route detection – replanning request

3.2 DSS Embedded Algorithms

The most striking aspect regarding evacuation management systems is the methodology on how a graph-based model is created, given a specific infrastructure. Graphs are commonly used to model the topological structure of internetworks in order to study problems ranging from routing to resource reservation. Area segments, such as rooms, corridors, stairs and lobbies, are modelled as nodes. The connections between adjacent segments are represented through arcs/edges. Thus, a static network representation $G = (N,E)$ is created.

Groupwised Evacuation Algorithms. MRCCP (Multiple-Route Capacity Constraint Planner) and CCRP (Capacity Constrained Route Planner) [8] are the most adaptable procedures to this problem not only because they compute near-optimal evacuation plans but also because their worst-case time complexity are very good for hard real-time applications. CCRP is the algorithmic procedure that has been selected for the purposes of the SAVE ME project. This is because CCRP has a better worst-case time complexity in contrast with MRCCP which also fits very well to evacuation scenarios but its scalability to large size networks is unsatisfactory.

Personalized Evacuation Algorithms. Personalized routing is the most important functionality of the DSS even if concerns a smaller number of people. The system must follow again the above mentioned algorithmic techniques with some basic changes. In case of a small number of disabled travellers the routes will be provided by shortest path computations, otherwise CCRP is the most effective way to provide the evacuation routes. One major difference between the personalized and the groupwised evacuation procedure is that evacuation routes may differ between people with different distance from a hazard area and people with different disabilities (e.g. a wheelchair user can only use the elevator and not the stairs). In case of more than one person with same special characteristics in the same place, the above mentioned groupwised techniques are applied in a personalized manner in order to reduce the computational effort. Generally speaking, an unassisted manual wheelchair user is almost 45% slower than an average person while an assisted is almost as fast as an average person [12]. Of course, wheelchair users cannot pass through the stairs. Results taken from [12] concerning different kind of disabilities used extensively from the DSS for the personalized evacuation module enhancing in that way the accuracy of the model by applying the special characteristics of each individual group. For example, if the edge type describes stairs then the new edge weight *weight(i,j)'* for the disabled travellers is computed as can be seen in (1),(2) and (3). According to [12] the values of the following parameters were set to: a=1.45, c=2.18 and b was set a very high value, since wheelchair users cannot use the stairs.

Reduced speed: weight(i,j)'= weight(i,j)**a* (1)
Wheelchair: weight(i,j)'= weight(i,j)**b* (2)
Walking sticks: weight(i,j)'= weight(i,j)**c* (3)

Rescue Team Planning Approaches. The Rescue Team planning is a very difficult procedure because the system has to combine different types of information and to decide an optimal scheduling plan for the rescuers. The main objective of this procedure is to secure the safety of the rescuers and of the trapped travellers. To this matter, there exist techniques based on fleet management and vehicle routing problem for collecting hazardous materials and scheduling vehicles under many constraints ([13], [14]). However, rescuers cannot be considered as vehicles with constant capacities. And this is because rescue teams can be divided through time cause of an urgent need (e.g. a rescuer may decide to help a wheelchair user to exit the building).

In the suggested approach, the Deadline-Traveling Salesman Problem(TSP) [1] is solved first. As is known, the TSP can be applied only to complete graphs. However, this is not the case for majority of the public infrastructures. To this matter, generalized shortest path algorithms were applied to create the complete graph that is needed to solve the following problem: *Given a metric space G on n nodes, with a start node r and deadlines D(v) for each node v, the Deadline-TSP problem is to find a path starting at r that visits as many nodes as possible by their deadlines*. The approach described above is presented in the following pseudo code.

```
program Deadline-TSP (Output)
{Pre-process: Create a complete graph G'={ S ⊆ N , E'}
for the subset S of nodes with trapped travelers by using
shortest path computations};
P = D-TSP(G');
{P ← Computed path from Deadline-TSP, P_1 has the
highest priority in the rescue operation};
begin
    For i=1 to NS (NS = nodes with trapped trav.)
        While (NumberOfRescuersNeeded(P_i)<
        NumberOfRescuersSent)
            For each RT in RescuTeams
                RescueTeam1=Min(Distance(RT, P_i));
                ShortestPath.SendtoRescueTeam1(P_i);
            End For
        End While
    End For
    If (!NodeInP.SentRescueTeam())
        AllRescueTeams.InformAboutHelpInNode(NodeIn
        P);
    End If
end.
```

Contraflow Configuration. Contraflow, or lane reversals, has been discussed as a potential remedy to solve tremendous congestion by increasing outbound evacuation route capacity [6]. With a given evacuation situation using an undirected and capacitated graph with multiple sources and multiple destinations, the problem is to find a reconfigured network by contraflow with the objective of minimizing the total evacuation time. This way, each connection obtains double capacity which means that almost double number of people can now pass through each connection. This has as a result much faster evacuation times and increased safety, especially in stressful situations.

4 Results

As a first step, in order to test the algorithms in the context of groupwised evacuations, multiple tests were realized. However, these tests are computer-based which means that the input data came from some statistical data regarding the daily movement of the passengers in the Monument metro station in Newcastle. In the final tests of the evacuation algorithms, a percentage of 80% of the graph nodes had initial occupancy. Moreover, this scenario included a huge number of travelers ranging from 150 to 600 and with congestion density ranging from 17% to almost 70%. The following figures present the overall results regarding the evacuation scenarios for different numbers of travellers. As is obvious from Figure 3, the evacuation times are higher when a hazardous event occurs. This is normal and the objective of the DSS is to reduce these times as much as possible but always in a heuristic manner. CCRP embedded functionality of the DSS produced all these evacuation plans in real-time and with very good overall egress times as can be seen in Figure 3. The GEM of the DSS may decide to split some travellers located in a specific node. This may have as a result the splitting of the traveller groups during the evacuation procedure. It is certain that it is difficult for travellers to follow this kind of guidelines. However this aims to avoid a congestion situation around possible bottlenecks during the evacuation procedure. Figure 4 presents the number of different groups generated by the GEM of the DSS in contrast with the number of the travellers.

As a further step, the DSS was tested successfully in real scenarios using real data from the sensorial systems in the two SAVE ME project pilot trials. The first one was held in the Colle Capretto tunnel in Umbria, Italy, while the second one

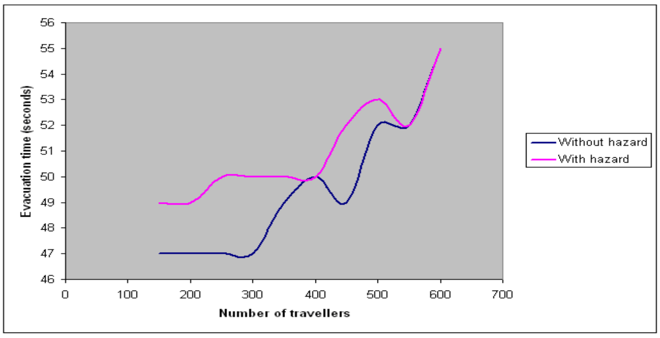

Figure 3: Evacuation times for different number of travellers

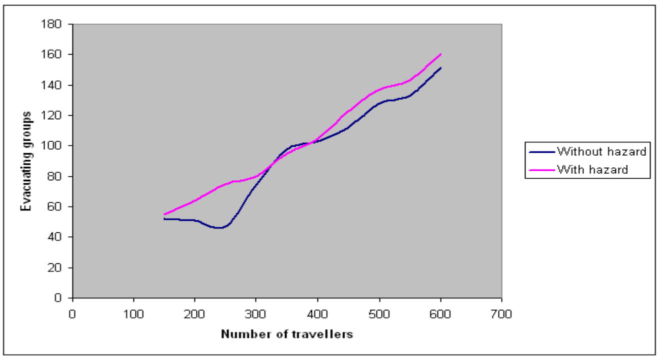

Figure 4: Number of evacuation groups for different number of travellers.

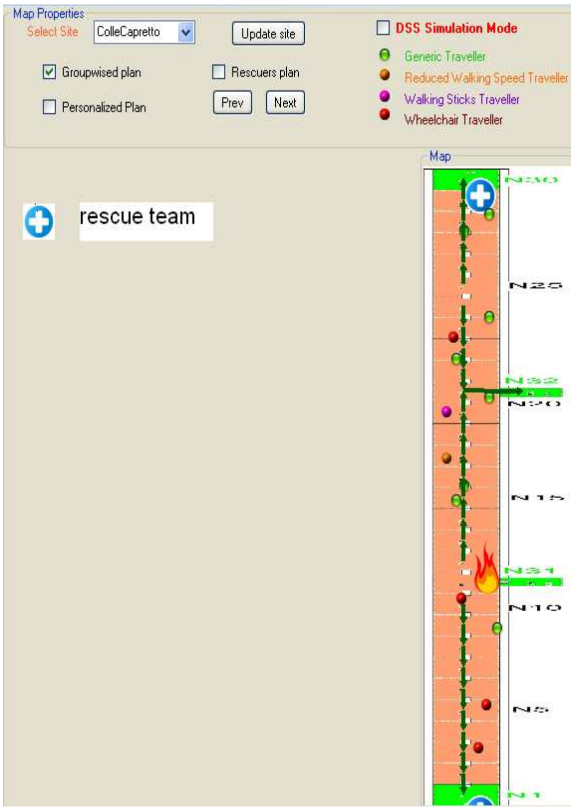

Figure 5: Groupwised evacuation plan in Colle Capretto trial.

was held in Monument metro station in Newcastle, UK. In both cases the DSS received real data regarding the environmental conditions and the travellers' localization and taking into account results from the crowd simulation module, it created in real-time the evacuation and rescue team plans.

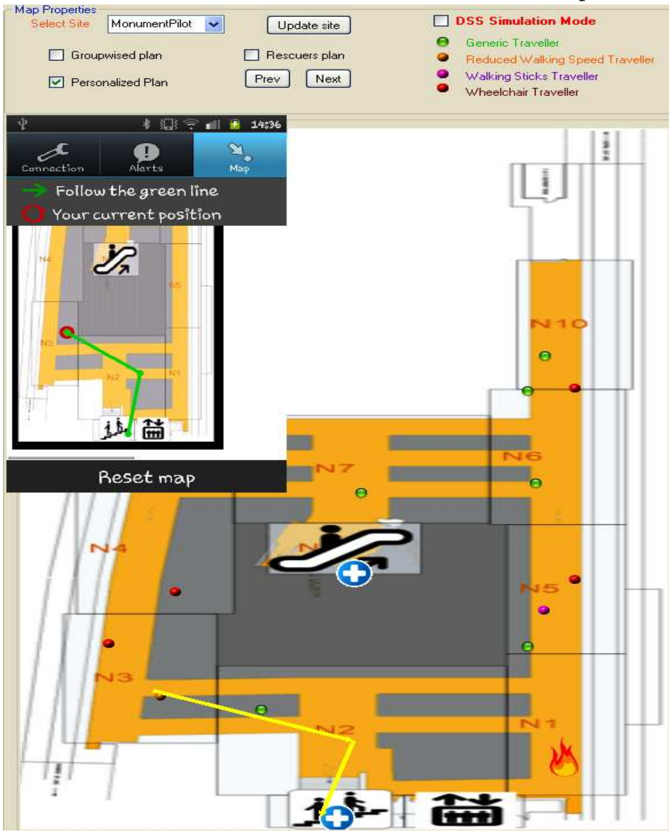

Figure 6: Personalized plan in Monument trial & Corresponding snapshot from the specific traveller's mobile app.

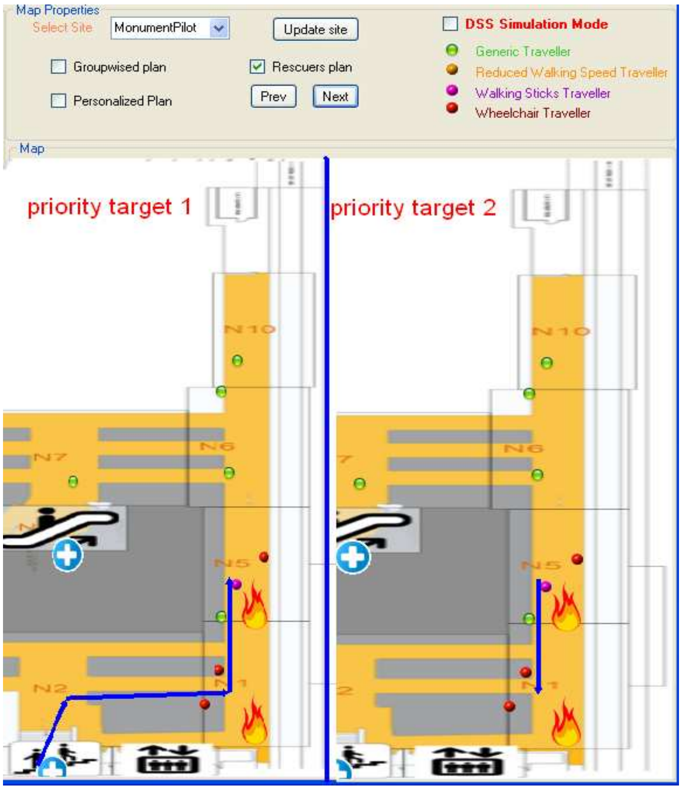

Figure 7: Rescuers' plan for the first team in Monument trial.

In addition it handled successfully the personalized communication with the travellers' mobile applications. Below are presented some snapshots of the DSS User Interface with the plans created during the two trials. Figure 5 displays the groupwised evacuation plan for the first trial, while Figure 6 shows the personalized plan of a specific traveller for the second trial and the corresponding visualization of the mobile application that the specific traveller received through the DSS service personalization platform. Finally, Figure 7 shows the rescuers' plans for the first rescue team. In the left part of the image is displayed the optimal path from the initial position of the rescue team to the first priority target and in the right part of the image the optimal path from the first target to the second priority target.

5 Conclusions – Future Work

Current work discusses a Decision Support System, designed and developed for the analysis of evacuation models and systems during hazardous events in public infrastructures. Initially, an overall state of the art analysis on evacuation planning was presented. In this part, different existing evacuation tools and their models were examined in order to have an overall view of the current research status in this field of study. As a result, a selection of these models was decided to be embedded in the DSS functionality. It should be noticed that the DSS delivers a flexible modular architecture, which allows different techniques and implementations to be employed for evacuation planning. The design principles were chosen such as existing components do not have to be changed principally, but only extended by specific functionalities or additional, new applications. A common evaluation framework and corresponding evaluation tools (benchmarking metrics through the production of log files, thresholds for safety impacts, reliability, functionality, application and system performance, etc.) are utilized in order to define the overall system safety level as well as to evaluate in the pilots the achieved system and modules performance in all criteria. Regarding the DSS module itself, it is anticipated that the information guidance accuracy to the safest exit (even gathering points if they are existent) should be over 95% for both group-wise and personalized routing. In this respect, as evacuation routes are heavily based upon the WSN network (events, people localization) and the crowd simulation, the accuracy of evacuation routes are affected by the accuracy of such information. However, as already described below, the replanning module of DSS ensures that the evacuation routes are estimated using the latest available and accurate information (localization, events, closed-nodes, etc). A future enhancement of the system would be to certify the implementations in order to expose the system to the web without risking the availability of resources.

Acknowledgements

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