Nat Hazards (2015) 75:57–69
DOI 10.1007/s11069-014-1304-3

ORIGINAL PAPER

Factors that affect rescue time in urban search and rescue (USAR) operations

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Received: 7 January 2014 / Accepted: 14 June 2014 / Published online: 29 June 2014

Abstract Recent structural collapses were studied in order to identify gaps in technology and to propose priorities in enhancing urban search and rescue (USAR) tools. The timelines of the events were examined with the scope of extracting critical factors that affect rescue time and can be used to define priorities in tools and technologies development, so that efficient and fast location, recovery and treatment of victims can be achieved. In this context, seven factors were identified: (1) best practices and lessons learned, (2) rescue technology, (3) community involvement, (4) information systems, (5) technology integration, (6) crisis management and (7) available budget. Each of these factors is reviewed, analyzed and discussed with the scope of providing future developments in tools and technology for USAR operations.

Keywords Prompt rescue · Tools and technology · Technology integration · Community involvement · Information systems · Crisis management · Best practices and lessons learned

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1 Introduction

Reports on structural collapses, reveal a persistent vulnerability and emphasize the importance of better integration of collective response to such emergencies (Alexander 2002). Besides earthquakes, which is considered a high catastrophic and unpredictable natural catastrophe (Alexander 2010a), other phenomena that give rise to entrapments are the blast effects due to terrorist attacks (Comfort and Kapucu 2006), industrial accidents and/or domestic gas escapes (Stewart et al. 2006), snow and ice avalanches (Barbolini et al. 2006), ground failure including mass movements and subsidence (Petrucci and Gullì 2009), volcano eruptions (Zuccaro and Ianniello 2004) and tornados (McDonald 1993). The above structural collapses were highlighted in the interim and experts report review of FP7 integrated project "Second Generator for Urban Search and Rescue Operations" ("SGL for USAR", www.sgl-eu.org; Alexander 2010b). Disaster impacts are especially high in urban areas as they affect large, densely populated regions, often involving high, extended building blocks with complicated street patterns, socially diverse populations with ethnic, religious and linguistic issues (Mäyrä et al. 2011). Therefore, USAR operations are considered time-consuming and technically demanding compared to sea, mountain or rural operations; this is better shown in Fig. 1.

Nevertheless, despite sustained, often heroic efforts, the relative number of rescued survivors from extended structural collapses remains small (Bartels and VanRooyen 2012). On the other hand, the number of structural collapses due to natural (e.g., Iran, 2003; Indonesia, 2004; Italy, 2009; Haiti, 2010; Japan, 2011), man-made disasters (e.g., Indonesia, 2002) or technological accidents (e.g., Holland, 2000; Russia, 2009; Canada, 2013) is increasing worldwide, raising the death toll of entrapped victims (EM-DAT The OFDA/CRED International Disaster Database 2014; EEA 2010; EERI 2011). To alleviate this,

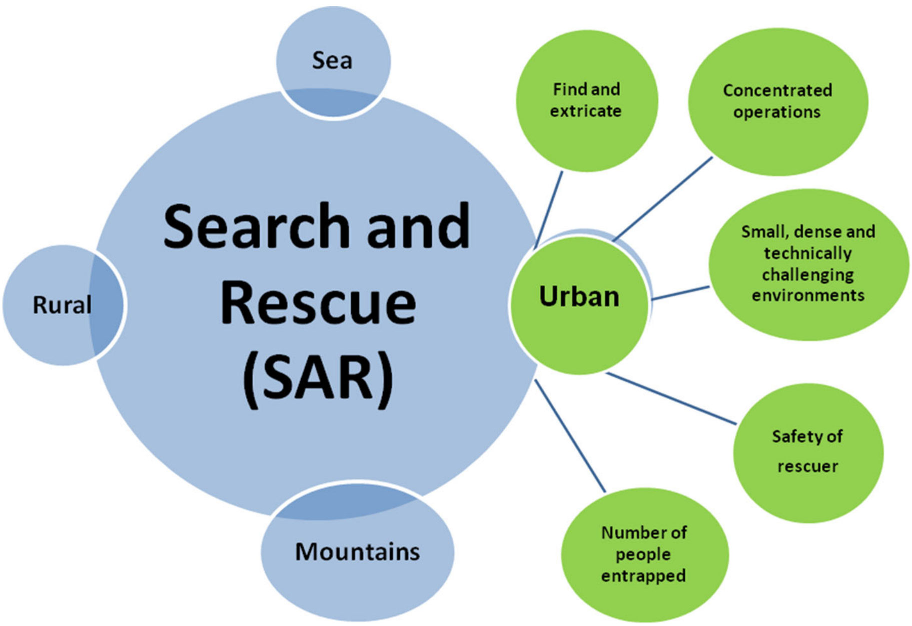

Fig. 1 The different environments of SAR operations and the main characteristics of USAR operations

there is a need to standardize all phases of USAR operations (deployment, search, locate, extrication, on-site medical support) and increase the speed of rescue efforts. All phases of the operations have unforeseen time frames as shown in Fig. 2. As disasters respect no borders, USAR operations standardization will contribute to the efficiency of both management and field operations, especially in the frame of international missions. As an example, 37 USAR teams from 21 nations were deployed in Taiwan after the Ji Ji earthquake on September 1999 (Chiu et al. 2002).

Searching under the ruins of collapsed buildings is actually a fight against time, as time is strongly associated with the chances of survival of the entrapped victims (Macintyre et al. 2006; Coburn and Spence 2002). Note that no single tactic is sufficiently effective on its own to ensure that a complete search has been conducted. Therefore, any technological or organisational advancement is more than welcome. In most cases, the local community response is characterized by spontaneous rescue attempts by survivors armed with simple tools or bare hands. Nevertheless, the most popular operational methods for locating entrapped victims are physical void searching, audible call-out, search cameras and fiber optics/boroscopes use, infrared/thermal imaging, electronic listening devices and canine searching (Wong and Robinson 2004). Each search method presents advantages and disadvantages (Civil/Military Coordination in Search and Rescue Operations Workshop 2002). Physical void search can be performed by untrained people without the need of special equipment; however, it is considered dangerous, it cannot locate unconscious victims and presents limited access to the voids. The audible call-out method presents the same advantages as above and can be used in conjunction with listening devices. Nevertheless, very young or physically weak people, as well as, unconscious victims cannot respond when the sound of knocking is too weak. Search cameras present the advantages of easy use, picture recording and remote viewing; however, size, cost, power requirements and the

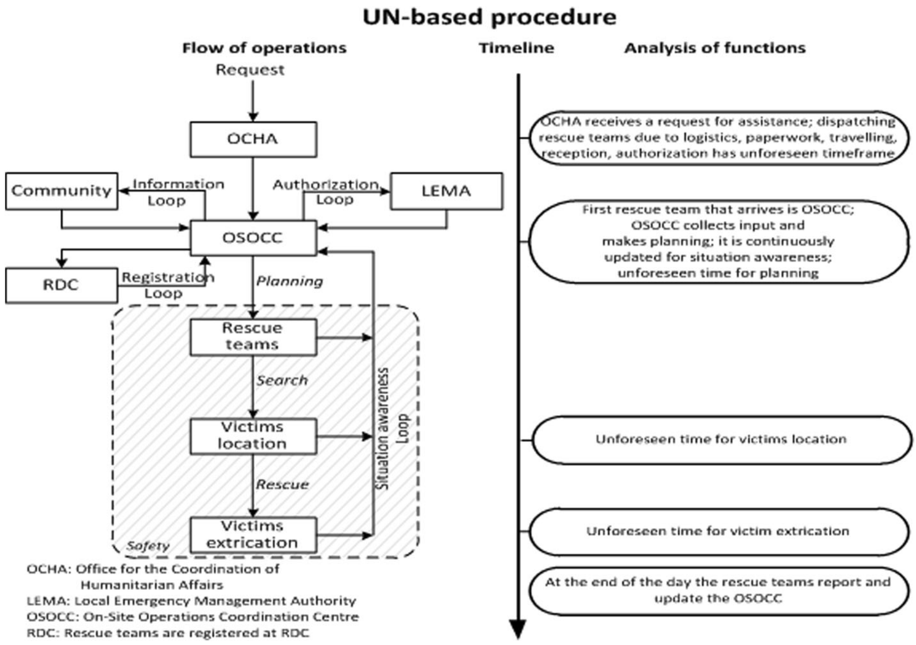

Fig. 2 INSARAG-based procedures: flow of operations, timeline and analysis of functions

limitation of line-of-sight reduce their wide adoption. Fiber optics and boroscopes can provide the general position and condition of the victims and are used for verification purposes prior the rescue effort; however, observation holes cannot be viewed in inaccessible voids or under limited light conditions. Infrared and thermal cameras are quite useful to survey large, open, dark areas and can see through dust and smoke but the presence of other sources of heat creates misreading. Electronic listening devices are used for covering large areas and by applying specific techniques (triangulation) can locate the victim position and/or identify faint noise/vibrations. Their main disadvantages are the limited acoustic and seismic range, the need to lower the ambient noise level and the fact that they cannot detect unconscious victims. Canine searching is ideal for screening purposes covering large areas in short time-periods. Rescue dogs can detect unconscious victims and potentially dead bodies (cadaver dogs). Nevertheless, the number of rescue dogs is limited, their performance varies and present short working time frames followed by rest times. Moreover, they can easily get saturated and frustrated (especially in the presence of dead bodies). No chemical sensor can catch the sensitivity of canines; however, they are exposed to many toxicological hazards and risks (Gwaltney-Brant et al. 2003). Other more advanced methods include the use of search robots (Murphy et al. 2001), autonomous camera-based devices (Dandoulaki and Andritsos 2007) and microwave systems (Chen and Norman 2000). Lately, chemically searching, mimicking canines' performance, is being also suggested (Agapiou et al. 2013; Huo et al. 2011). The method is based on the detection of biogenic volatile organic compounds (VOCs), released continuously or periodically, from human tissues (e.g., skin, lungs) and biological fluids (e.g., sweat, urine) forming the human scent chemical profile (Mochalski et al. 2012, 2013, 2014).

In addition to the deployment phase that is very critical, good planning is essential for fast rescue. It involves, among others, identifying the most promising areas to search and the best potential locations for survivors. Thus, reliable classification of collapsed buildings for fast damage and loss assessment is necessary (Schweier and Markus 2006). Fast and efficient searching is best performed with the latest proven technologies that confirm the likely presence of voids and potential entrapped survivors. These allow focusing rescue efforts where the person is likely to be entrapped and recovering the survivor as quickly and safely as possible.

The present paper focuses on identifying factors that affect SAR time in all phases of USAR operations. The analysis of these factors aims at finding gaps and proposing enhancements in tools and technology. As part of an EC FP7 project ("SGL for USaR", www.sgl-eu.org), that investigated integration of different (optical, acoustical and chemical) sensors for USAR operations and carried out consultations and workshops, the accumulating material is presented ("SGL for USaR" project web-site; workshops; conferences; technology forum). Although there has been extensive research in the impacts of natural or man-made disaster, this is, to the best of our knowledge, the first study focusing on factors affecting fast rescue; a complex and multi-dimensional operational issue, that always appears in the disaster zones after building collapses.

Survival under the building rubbles (e.g., reinforced concrete, framework of steel or reinforced concrete, unreinforced masonry (bricks), glass, wood, stone constructions) is strongly time-dependent. Therefore, there is a need to decrease the time to rescue surviving victims after major (natural or man-made) disasters. The aims of the present work are as follows:

- To identify and highlight the factors that affect the rescue of disaster surviving victims based on the time lines of past events (Haiti and L'Aquila disasters) and

- To propose new rescue detection tools and devices which correspond to state-of-the-art technologies for planning, situation awareness and mission security.

Taking into consideration the proposed factors, the operational capability of rescue teams can be improved, the rescue response time will be shortened and better planning and harmonization of field operations will be achieved; especially in international missions.

2 The timeline of response

In two recent natural disasters, those of Port au Prince (Haiti, 2010) and L'Aquila (Italy, 2009), close examination of the timelines has revealed a number of issues presented in Table 1, that can delay substantially USAR operations.

Two additional issues need to be noted: the first is the different times needed for the different phases of USAR operations; those of planning, preparedness, search, rescue, support and recovery. The second is the "unofficial", yet significant, role of the impacted communities in USAR. In large-scale disasters, relatives and neighbors are likely to be the first responders, as they will be conducting USAR tasks long before the arrival of USAR teams. The catalytic effect of the people from the impact area was noticed in different countries (Palm and Ramsell 2007; Sharkansky 2007).

3 Fast rescue: a multi-dimensional problem

At least seven factors (dimensions) were identified in the problem of prompt rescue in USAR operations in collapsed buildings. These are as follows:

1. *Best practices and lessons learned* cover the informed evaluation and analysis of past experiences available on demand as the USAR mission develops.
2. *Rescue technology* involves the development and optimization of enhanced casualty assessment, monitoring and extrication tools.

Table 1 Issues that prolong USAR operations

The mobilization and dispatch of rescue teams, especially from abroad
Authorizations and permits
Logistics of the operations
Overall situational awareness, including risk analysis and safety assessment
Planning and assignment of the teams together with continuous security briefing
Re-searching in one building after removing debris (this is usually a task for heavy rescue teams)
Drilling and crane lifting
Communications with teams from different nations
Building/ruin stability evaluation: unsafe buildings slow down the operation. A large number of specialized structural engineers are needed for a prompt evaluation of the stability of buildings and ruins
Empirical-based triage for prioritizing searching is not sufficient in many cases (it might or might not provide objective analysis of voids/survival spaces in the building)
Human resources and equipment for search are always limited. Canines are the main searching tools

3. *Community involvement* establishes collaborative relationships between professional rescue teams and community-based first responders to achieve significant leverage of expertise and resource.
4. *Information systems* involves identifying, collecting and managing multiple data streams and transforming them into information in order to deliver better high-level planning and timeline situation awareness.
5. *Technologies integration* deals with the validation and integration of state-of-the-art technologies.
6. *Crisis management* deals with adaptive and scalable management systems based on the understanding that significant collapses are chaotic.
7. *Available budget* impacts on purchase but also on the fast deployment and use of systems and technologies. At long term, it can have a significant impact on the development of new systems and technology.

3.1 Best practices and lessons learned

Studies of past disasters can provide with lessons about how to achieve faster rescues and, more specifically, how to reduce the time of search and extrication. Despite numerous efforts (e.g., OFDA/CRED International disaster database, UNISDR, Canadian disaster database), there is still no systematic way of reporting on past disasters. Unraveling the details of past events opens the doors to discovering routes to fast rescue. However, the underpinning issue in every USAR operation is the safety of rescuers. Equipped with the right technology, which monitors safety parameters continuously, and simultaneously warns and informs the USAR effort about the ever-evolving situation in the ruins, is a good starting point. Consequently, any strategy for reducing the time of rescue needs to start from safety and then prioritizing those efforts that accelerate every aspect of the rescue effort. The highest priorities in fast rescue are presented in Table 2 ("SGL for USaR" project web page; workshops; conferences; technology forum).

It is clear from the priorities presented previously that two distinct issues arise: supply of continuous, updated and accurate information and developing better tools for extrication. Furthermore, concerns such as technologies for early detection and location are also important for time reduction, especially in mass disasters.

3.2 Rescue technology

"The right tools for the job" will reduce the time needed to recover casualties from collapsed structures. There have been substantial enhancements in the tools and systems available for the recovery of people from wrecked cars, and the time for specialist rescue tools is long overdue. The current state-of-the-art relies too much on adapted construction of civil engineering equipment. Using such tools in a USAR setting, places extreme physical demands on the rescuer, who tires rapidly and so needs to be constantly substituted to prevent exhaustion. This situation delays rescue and reduces the chances of survival. The weight and designs of the current generation of tools is critically limiting. For example, the current maximum lengths of power hoses associated with pneumatic equipment are too short to enable such tools to be used deep inside collapsed structures, and also too short to ensure that fumes and exhausts from the generators do not disrupt the USAR operations inside the rubble. Innovation in battery-driven systems and designs to give lighter tools is also needed. Enhanced designs and materials for tools that move, cut,

Table 2 A rescuer's charter of priorities for more efficient USAR operations

Correct decision-making at the beginning at political level (clear picture of what has happened, scale of disaster, available resources inside the country, need for requesting help)
Early detection and location
Safety of rescuers
Better concrete cutting tools
Better logistics (detailed description of the tools needed, especially at the point of arrival)
Better information and planning
Tools that can be easily deployed
Satellite support
Collaboration among international rescue teams
Adaptability of tools to events
Fast transportation of rescue teams to the scene of disaster
Improving situation awareness
Accurate knowledge of the disaster scale
Better use of existing technologies and methods
Better training
Context information
Obtaining information from the media

break- and chip-reinforced concrete, brick and cladding without putting survivors' safety at risk and exhausting the rescuer will also reduce rescue times. Such systems, ideally, will have flexible functionality to adapt to different materials and thicknesses, as well as, enable drilling in the direction that is considered optimum (which may often mean drilling into overhead structures).

The envisaged improvements in performance may be delivered through the use of lasers, high-water pressure systems, automated stabilization and anchoring, and even controlled micro-explosions.

Innovations and enhancements needed to create a new generation of rescue, need to be led in partnership with the manufacturers of rescue equipment. Currently, the supply chain and market for extrication tools is fragmented and, as noted above, mostly focused on tools used in building construction. Few companies have the knowledge and insight required to guide their inherent expertise to develop tools for USAR operations, and they will need to pay attention to the priorities of rescuers, as summarized in Table 3.

3.3 Community involvement

The classic USAR model envisages three phases: planning, search, and rescue. However, such a process is neither straightforward nor linear for overlaying these three essential stages, due to the activities, interactions and feedback within the affected community. The community, for some analysts, is considered the most critical factor in accelerating the emergency response (King 2007). There are many recent examples of how communities under significant stress exploit state-of-the-art communication technologies to analyze, organize and prioritize community-led activities (Dandoulaki and Halkia 2010). Applications that integrate and manage such activities and enable ubiquitous technologies to provide on-site real-time data and measurements can be seen to massively accelerate the acquisition of reliable information, and the transmission of important search, rescue,

Table 3 Priorities for next generation rescue tools and technology

Formulate and adopt standardized rescue techniques
Implement quality assurance schemes for rescue equipment
Implement quality assurance schemes for training rescuers to use equipment
Create and maintain USAR user groups and networks to ensure that equipment manufacturers, R&D and equipment design teams are fully aware of user needs and experience
Reduce weight wherever possible of all rescue equipment
Eliminate excessive hand/arm vibration from tools and reduce the 'white finger' problem for the operators
Increase the useable length of power hoses to allow rescue tools to be used further into collapsed buildings while petrol/diesel generators and their fumes remain in fresh air
Produce improved battery-operated tools that are more portable, light and negate the use of generators/power units and their problematic fumes
Consider the effect and impact of the rescue tools to the casualty in terms of danger of dust, water and reduce the impact where possible
Increase the effectiveness of the tools employed for cutting, breaking and chipping, thereby reducing the extrication times of the trapped victims
Reduce the noise levels of the tools to allow better team communication and reduction of operator's health and safety issues and to enable the evacuation signal to be heard
Production of smaller, lighter tools with increased effectiveness in confined spaces and reduce manual handling issues
Consider tools with their own light source to illuminate the working area
Consider a multi-functional, multi-headed tool to reduce weight and speed up the extrication process
Consider the problems of mobilizing heavy equipment through tunnels and voids strewn with rubble and offer solutions
Carry out in-depth studies into the United Nations INSARAG, FEMA (USA), Australia and New Zealand equipment and rescue techniques

treatment and recovery messages. Skillful engagement with, and leadership/management of, the community-based responses has the potential to reduce the time over which chaos is the prevailing feature, and significantly accelerate rescue operations, considering the affected community: response involves thousands of individuals undertaking the immediate rescue and care of straightforward cases; recovers personal goods and resources to facilitate resilience and subsistence during the early post-incident phase; supplies, verifies and collates mission-critical information; provides first aid, hydration and nutrition; has tools for initial responses; and identifies potential rescue sites.

Table 4 is a succinct summary of collaboration and interaction factors, and in all of this, cultural issues and ethics are essential in understanding and enhancing community responses. This is a key area for improvement to achieve better coordination and integration of community-led responses to convert chaos into a focused effort. Preliminary actions to enhance USAR capability through community involvement might well include the tools presented in Table 5.

In contrast, the "professional" (rescue) teams are numbered in the hundreds and arrive usually post-event; they deal with complicated situations and apply triage for USAR operations. Although many people may be buried, cases are extricated one at a time; they establish a safety culture and provide either medical support by disaster medicine approach (use the resources for the vast majority, e.g., shelter, food, and triage) or by intensive care approach (use the resources, e.g., high-tech expensive equipment, to deal with individuals). Such teams organize themselves and their operations to follow protocols and

Table 4 Features of community after a disaster

Has	Needs	Will
Information	Welfare	Engage with USAR teams constructively or destructively
Motivation to help	Management	Work independently
Resources	Information	Remain after recovery
Useful skills	Psycho-social support	Turn on itself if left unsupported

Table 5 Actions to enhance USAR capability through community involvement

Fast and wide-scale deployment of essential but inexpensive low-tech tools
Fast re-establishment of high capacity telecommunication networks
Rapid deployment of embedded USAR professionals to act as “team leaders” development and distribution of an emergency information collection application that is activated post-event
An internationally adopted USAR protocol to address and effectively manage cultural issues

methodologies, for example on a national basis or alternatively on INSARAG UN approach (INSARAG Guidelines 2012; INSARAG web-site).

3.4 Information systems

Informed decisions in USAR operations in collapsed buildings are crucially dependent on reliable situational awareness. Organized USAR operations have developed different approaches to develop situational awareness of the search site. The most basic approach is to collect information by word-of-mouth from relatives, neighbors and other witnesses, as well as on-site observations. This is confounded by conflicting information and deliberate attempts to gain priority treatment. It is charged with uncertainty, false assumptions and consequently increased safety risks. Such approaches are enhanced by objective measurements that improve search and rescue teams’ situational awareness, for example: environmental measurements, chemical detection and technical assessments of the stability of the rubble. Table 6 summarizes the rescuers’ information priorities as recorded in a relevant technology forum (“SGL for USaR” Technology forum).

3.5 Technologies integration

Although a number of mature and emerging technologies for USAR exist and have been proven in a variety of scenarios, not necessarily involving collapsed buildings, most approaches and systems have not been properly tested, validated nor proven in applications regarding collapsed structures. Methods for enhancing USAR systems’ efficacy and reliability may be seen to be based on effective integration of complementary technologies onto a single platform. Such an approach has the following advantages: provision of a fast overview of the location of voids and, potentially, victims; improvements in the accuracy and sensitivity through orthogonal sensing approaches; reduction of false alarm incidence rates; provision of flexibility in deployment, with a single deployment for multiple search and rescue responses; enabling technology-based responses to be combined with community input; provision of new applications and markets for existing technologies. Table 7 summarizes candidate systems that await integration to generate significant and rapid advances in USAR capability (“SGL for USaR” web-site).

Table 6 Search and rescue information priorities

General quick assessment of victim location
Use of situational awareness models like the Endlsey model (data, information, decision)
Satellite images (immediately available), buy on-site service
Normal area assessment with helicopter or airplane
Use of balloon with video camera
Unmanned helicopter with camera and real-time data transmission
Continuous monitoring
Knowing the structural system and the type of building materials
Unattended monitoring of collapsed buildings
Normal inspection by structural engineer for assessment
Use of mobile phones of victims
Information integration and fusion

Table 7 Candidate technologies for integrated USAR systems

3D scanner
Video signals
Audio signals
Chemical signals
Hyperspectral imaging
Wall penetration radar
Ground penetrating radar (GPR) and other geophysical methods
Intelligence with video
Satellite images
Accelerometer based methods
Radio technologies
Unmanned aerial vehicles (UAV) and robotics
Smart phones
Mobile phones (location and identification)

3.6 Crisis management

All large-scale disasters, whether natural or man-made, are different. The only commonality is great complexity. Large-scale natural disasters have multiple impacts that operate over different timescales: loss of life and property, spread of diseases, loss of the means of production, damage to, and loss of infrastructure, loss of cultural assets, and loss of intellectual capital. Large-scale disasters do not respect international borders. Crises are expected to surprise humans even more in the future; they will concern "unthinkable events in inconceivable contexts" (Lagadec 2006).

The prevailing chaotic conditions found in all large-scale collapses strongly effect how rescue teams are dispatched and deployed, what their priorities will be and what technology they will use. Every event has different timeframes for planning, search and rescue. Most importantly, large-scale disasters have impacts on the type and quality of information (events, data, intelligence) that is received and sent by the planning and coordination entities, as well as, on the amount, accuracy and completeness of the information transmitted from the disaster zone.

3.7 Budgets available

State-of-the-art in current USAR operations involves the purchase, integration and deployment of several best available technologies. The effective use of such systems is therefore specific to the application, and currently lacks cohesion, technological standardization and operates at potentially high cost. Additionally, operating costs reflect roughly 20 % of the purchase cost per year, spare parts and subscription services (e.g., earth observation and GSM services). Budget limitations of relevant services and organizations involved in USAR operations pose severe limitations for enabling the evolution of ameliorated technologies and services. The concept of integrating and standardizing technologies into singular and coherent platforms may not only alleviate cost dimensions, but also intrinsically overcome the deficiencies propounded by the lack of technological standardization. The operational advantages enabled through such systems are plentiful and include the capacity to cope with different USAR environments (location and disaster type), the mobilization of diverse end-users, and combination of the capacities afforded by the available technology suite. A substantial business model therefore exists for integrated systems and technologies in USAR operations. This is, however, a delicate and challenging problem, compounded by the fact that current purchasing budgets for rescue equipment are fragmented at local, regional and national levels. Therefore, the successful business model must require further study, decided and defined in collaboration with end-users. It may be that multiple models exist for different applications and for this purpose they must be tended toward the respective stakeholders, which include the security market (police and army), in addition to USAR bodies responding to natural disasters.

4 Conclusions

The proposed work has highlighted the following seven factors that can inspire developments in USAR operations in tools and technology; best practices and lessons learned, rescue technology, community involvement, information systems, technology integration, crisis management and budgets available. The selected factors can serve as a basis for practical developments. Advancing all these factors is the key for getting faster decisions and improving reaction times.

Acknowledgments The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007-13) under grant Agreement No. 217967; "SGL for USaR" project (Second Generation Locator for Urban Search and Rescue Operations—www.sgl-eu.org). The authors would like to thank Geert Seynaeve (ECOMED bvba, Belgium), Mike McCarthy (Fire Service College Moreton in Marsh, England), Claude Picard (Entente Pour la Foret Mediterranéenne/Centre d'Essais et de Recherche de l'Entente, France), Nelson Garcia Jacinto (Guarda Nacional Republicana, Portugal) and Raimo Rasijeff (South-Savo Regional Fire Service, Finland) for proving input and for constructive discussions.

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