Progress in Disaster Science 9 (2021) 100132

Contents lists available at ScienceDirect

Progress in Disaster Science

journal homepage: www.elsevier.com/locate/pdisas

Regular Article

Integration of smart watch and geographic information system (GIS) to identify post-earthquake critical rescue area part. II. Analytical evaluation of the system

M.S. Hossain [a,*], K. Chaitanya [b,*], Y. Bhattacharya [c], M. Numada [b], A.S.M.M. Kamal [a], K. Meguro [b]

[a] Department of Disaster Science and Management, University of Dhaka, Bangladesh
[b] Institute of Industrial Science, The University of Tokyo, Japan
[c] Department of Systems Engineering and Science, Shibaura Institute of Technology, Japan

ARTICLE INFO

Article history:
Received 9 September 2020
Received in revised form 28 October 2020
Accepted 1 November 2020
Available online 10 November 2020

Keywords:
Smart watch
Earthquake emergency response(EEMRS)
Post-earthquake initial situation assessment
Trapped victims

ABSTRACT

The efficient allocation of resources in the aftermath of an earthquake in an affected area largely depends on the identification of post-earthquake critical rescue area. This paper is the second part of the companion paper on the integration of smart watch and geographic information system (GIS) to identify post-earthquake critical rescue area. In the first paper, we proposed a new system through an application installed on a wearable device to dissipate the information of trapped victims called the Earthquake Emergency Micro Response System (EEMRS) Hossain et al. (2020) [27]. In the current paper an analytical model is developed to evaluate the effectiveness of it in the search and rescue (SAR) operations. The information dissemination formulation is postulated through observations and interactions with experts. The process of local first responders' immediate post-earthquake activities from dispatch to extricating the trapped victims at the affected area is carefully calibrated with the firefighter activities recorded in the aftermath of Kobe earthquake. Evaluation using the developed analytical method imply that the increase in use of smart watches in earthquake prone areas can significantly increase the extrication efficiency of firefighters. In addition, this proposed model can be used by emergency managers to know the robustness of their post-earthquake initial situation assessment techniques.

1. Introduction

Post-earthquake initial situation assessment is considered to be essential for efficient earthquake emergency response. It is necessary to know the extent of damage area and location of trapped victims in order to determine where local first responders need to send their resources after the earthquake. Without accurate and holistic initial situation assessment, there is a high likelihood of improper resource allocation, especially during the first twelve hours. For example, in the case of Ji Ji Earthquake, most urban search and rescue teams concentrated their efforts in the Nantou prefecture as it was the earthquake's epicentre [19]. However, Taichung prefecture had the highest number of recorded deaths (1177), and yet fewer (eight) rescue teams. For this, the Taiwanese government was blamed on account of imprudent urban search and rescue team's allocation. To allocate the resources efficiently to the earthquake affected areas, [24] proposed a dynamic optimization model. In another work Multistage stochastic program (MSP) was used to deploy the urban search and rescue team optimally [17]. EPEDAT (The Early Post-Earthquake Damage Assessment Tool) is to estimate real-time loss to support the emergency response decision [23]. Ghosh and Gosavi (2017) elaborated semi-Markov model to quantify the hazard rate and to estimate the restoration time after an earthquake [25]. A scenario based model, which is the combination of CIA-SIM and Delphi method, was proposed to evaluate the earthquake emergency management effectiveness by extracting the earthquake emergency key elements [66]. A Bayes decision procedure model was developed by Nojima and Sugito (1999) to optimize the process of post-earthquake emergency response and their model suggested that prompt information collection is essential to emergency response [41]. Chiu et al. (2020) proposed indicators for post-disaster (earthquake and rainfall-induced disasters) search and rescue efficiency by using progressive death tolls [20]. A rescue model based on hierarchical Voronoi diagram considering high altitude rescue, street human resources and road transport relief is proposed by [43]. As there seems to be absence of a direct approach or model which is capable to evaluate the post-earthquake information collection techniques, this research aims to develop a simplified numerical model to evaluate the post-earthquake initial assessment methods. The proposed model can be used by emergency managers to know the robustness of their post-earthquake initial situation assessment techniques, which will help them to take timely initiatives for

* Corresponding authors.
E-mail addresses: shakhawat.dsm@du.ac.bd (M.S. Hossain), chaitugk@iis.u-tokyo.ac.jp (K. Chaitanya).

http://dx.doi.org/10.1016/j.pdisas.2020.100132

awareness and preparedness for proper response. Based on past working methods and research some of the common methods of initial situation analysis techniques are discussed in the current manuscript.

1.1. Integrated disaster management system

The traditional approach to disaster management used to be response orientated [44] where actions were taken to minimize the impact of the disaster in the aftermath of the events with minimum focus to disaster risk reduction. However, increase in the amount of loss of life, property and associated impact has improved the understanding and brought forth the importance of a proactive approach in case of disaster resulting in the development of an integrated disaster management system [30]. Also, in the past years, the focus of disaster response has greatly changed to pre-disaster prevention efforts and coordinated reconstruction activities to strengthen the capacity of the population, reduce their vulnerabilities, develop pre-disaster plan, ensure effective response and long-term development [36,64]. Therefore, many nations follow an integrated management system consisting of continuum of inter-related actions namely prevention, preparedness, response and recovery. The prevention and preparedness phase plays a vital role in minimizing the damage and saving lives of the population in case of catastrophic disasters like earthquake [12,39]. According to UNISDR, (2009) prevention includes structural and non-structural activities like retrofitting, enforcement of building code, land use planning, vulnerability analysis, awareness raising etc. to reduce the likelihood of disaster by avoiding existing risk or creation of any new risk along with reduction in the adverse impact of a disaster [47]. On the other hand, preparedness phase involves improving the capacity to anticipate, respond to and recover from the residual risk through public education, training, developing early warning system and preparing contingency plan [30]. Several studies discusses how these activities and disaster education prior to an earthquake hazard can help the people in prompt decision-making and quick manage coordinated response in times of disaster [11,13,52]. The next phase is response, which largely involves evacuation, search and rescue and emergency relief in order to save lives, reduce the health impacts by ensuring public safety, and needs of the affected population (UNISDR, 2009) [47]. And, the last stage is recovery where lifeline utilities are restored and buildings are reconstructed with a view to 'build back better', considering the lessons learnt from the past. Therefore, an integrated management system is an integral part of disaster management for comprehensive risk evaluation, and to mitigate the impacts of hazards and reduce the risk of disaster [46,52]. This study mainly focuses on how information management system can help us to achieve effective and efficient response after a catastrophic earthquake. There are also several instances given in the study conducted by World Bank (2019), that discusses how Information and Communication Technology (ICT) helps in each phase of integrated disaster management cycle through development of tools, such as seismic monitoring system, communication and prediction technology. Technological advancement has enabled us to develop disaster management information system which includes real-time information obtained from image monitoring tools, communicate the risk and raise awareness through risk visualization and or artificial reality [57].

1.2. Thematic literature review of initial situation analysis techniques

The purpose of this subsection is to provide a thematic literature review of the methods which are usually used for post-earthquake initial situation assessment. They are smart watch, remote sensing, Unamanned Aerial Vehicles (UAVs), emergency call, mass media, Fast/Field reconnaissance survey and social media. The thematic literature review of the each method will provide the potentiality of each method for initial situation assessment. The detailed description of methods are given below:

Smart watch (proposed): In future, smart watches will be widely used due to their convenience, affordability, functionality, and recognition of physical activity [56]. Pradhan and Sujatmiko (2014) mentioned that smart watch could be worn constantly in all different contexts when other devices may not be viable [45]. The major difference between smart watch and smart phone is that by using smart watch it possible to monitor individual health. Seizure, posture and emotional state detection, heart rate, temperature and daily activity monitoring etc. are examples of application of smart watches in health science [16,29,31,33,35,37,40,48,63]. However, smart watches are an emerging technology and research with these devices is at a nascent stage; this research considers smart watch as a new post-earthquake initial situation assessment tool due to its potential to monitor daily activities and some basic health parameters. In our first paper, we have proposed Earthquake Emergency Micro Response System (EEMRS) which integrates smart watch and GIS to identify the post-earthquake critical rescue area [27].

Remote Sensing: Remote sensing data are considered as a natural choice for disaster monitoring, both natural and anthropogenic, because of wide area coverage and the possibility of fast processing [22]. Remote sensing plays an important role in all the disaster cycle activities, including response, recovery, mitigation and preparedness, however, its most critical role is in monitoring earth data during post-event (response) phase. The characteristics of earthquake, include factors such as sudden onset, unpredictability, wide impact area; requiring a time sensitive response, which makes remote sensing a useful tool to grasp the actual extent of disaster, damage level of infrastructure, and accessibility to the disaster zone [61]. Such kind of information can be very valuable for an incident commander for SAR operations, logistics, and evacuation planning. The approaches used to extract post-earthquake damage information's are visual interpretation, automatic or semi-automatic classification using optical or SAR imagery, pre- and post-earthquake building height techniques, 3D change detection etc. [61]. However, every approach has some limitations. In case of visual interpretation method, its advantages include the fact that it is the most straightforward and accurate method, while its disadvantages include the requirement of a very high resolution data which can be expensive, subjectivity in visual interpretation, the combined need for both pre and post-disaster data, dependency on weather, and its time-consuming nature [8,18,26,50,51,58,60,65].

In the proposed research we are mainly concerned with the minimum time required to get satellite imagery-based post-earthquake situation assessment with high accuracy. According to UNOSAT's rapid mapping operational framework, first 24 hrs is assigned for preliminary situation maps and 72 hrs is assigned for the situation analysis updates [6]. The Centre for Satellite-based Crisis Information of the German Aerospace Centre produced damage map for both Haiti earthquake (2010) and Van earthquake (2011) by using cloud-free image based on visual interpretation method approximately 72 hrs after the earthquake [61]. However, in case of Sichuan earthquake (2008) the National Disaster Reduction Centre of China (NDRCC) produced first damage map within half an hour of the earthquake. Almost 1300 images from 22 sensors were received and processed by NDRC for a better understanding of the situation of affected area [34]. In summary, post-earthquake information from remote sensing depends on both pre- and post-earthquake satellite image availability.

Unmanned Aerial Vehicles (UAVs): In general, satellite images, both optical and SAR images, are preferred for post-earthquake rapid loss and damage assessment as it is possible to get the desired images within the shortest possible time. However, they have several disadvantages which include, image resolution, cloud coverage and need for optical imagery, illumination conditions of the affected areas at the time of satellite passage (at very high latitudes), acquisition conflicts, heavy geometrical distortions etc. can cause delay of the desired images [15].

UAVs are considered to be a good alternative when desired satellite images are not available for post-earthquake rapid loss and damage assessment [15]. They have previously been used for identifying building condition and damage characteristics in post-earthquake scenario [38], and currently the European Commission is evaluating the prospect of UAV images as an alternative or complementary source for after disaster imagery during emergency situations and in a rapid response and mapping background [2].

Emergency Call: Emergency services and rescue services are institutions, which provide public safety and health during various emergencies. Some of these departments exist exclusively for serving definite types of emergencies. At the same time others deal with ad-hoc emergencies as part of their normal responsibilities. To prevent the safety of people and their property, emergency response services are usually at the core of organisations to respond to events that pose a threat [62]. In past few decades, how to tackle large scale incidents has become a popular focus due to several global incidents and accidents [9,10]. In general, emergency services have one or more reserved telephone and/or mobile numbers to receive critical emergency calls. When a call is originated from a landline phone, the number determines which dispatch centre is appropriate for the location and the calls are transferred there. If the call is originated from a cell phone, the call will be first addressed then transferred to the appropriate dispatch centre from where the emergency responders will be sent to the location of the emergency.

Mass Media: Even though social media (Facebook, Twitter) usage growth is very high and rapid, mass media is still considered as a more effective vehicle for mass communication after disasters and also for the collection and dissemination of crisis information [49]. Media, according to Joseph Scanlon (2011), plays a vital role before, during and after an incident while serving as a source of public information. Their reports can influence public understanding during the disaster aftermath which can often times complicate disaster response and therefore must be observed and handled with caution [54]. Undoubtedly, mass media has the potential to gather and transmit key information, i.e. trapped victim's location and damage level of the affected area for emergency manager [21].

Fast Field Reconnaissance Survey: To know the severity and distribution of damage, it is fundamental to accomplish a fast reconnaissance of the whole earthquake affected area to facilitate the rescue and evacuation operations [59]. There are different types of post-earthquake building inspections (PEBI) just after the earthquake such as, quick or initial, rescue, rapid, detailed, and engineering evaluations [59]. Quick (or initial) and rescue inspections are considered in the early stage of emergency phase. Quick (or initial) reconnaissance's purpose is to measure comprehensive damage of the affected area and is focused on identification of rescue sites by identifying total numbers of collapses or severely damaged buildings. The purpose of the rescue inspection (short-term assessment) is to determine the safety of rescuers as well as to detect the possible hazard for victims or rescue workers. The quick and rapid inspections are easier to carry out and require less time and experience than a detailed one. Usually, quick-PEBSA (Post-Earthquake Building Safety Assessment) is completed within hours after the event, although it depends on the severity of the disaster. Each Local Reconnaissance Team (LRT) composed of two or three members, one of whom is a trained technician, usually takes around 10 to 30 s to complete the survey of one building. When LRT identifies a collapsed building with trapped victims, they must immediately report to the local authorities and Search and Rescue (SAR) teams as victim survival probability can decrease with time [59].

Social media: Social media are known as a combination of internet-based tools that allow the exchange of user information to another single or group of users through conversation and interaction [7,28,32]. Due to the advancement and availability of internet network, social media has become more and more popular. Facebook and Twitter are considered to be the most popular social media platforms. Facebook has 2.2 billion monthly active users, and Twitter has 336 million monthly active users [[1],4]. In the last few years, it has been shown that social media tools can play a vital role during crisis response [55]. For example, emergency responders have used social media as an important additional communication channel in 2010 Haiti earthquake [14,53]. Another good example is Hurricane Sandy in 2012 where first responders used social media as main communication with the public [53]. Tomer Simona et al. (2015) discusses the advantages of social media in emergency situations. According to her, these advantages are- 1) Important and timely information can be acquired; 2) Changing pathways for emergency information dissemination; 3) Transforming emergency tracking; 4) Reliable source of information when other sources are overburdened; and 6) Re-cheking for misinformation by itself [55].

The objective of this paper is to develop an analytical method to evaluate the post-earthquake initial situation assessment techniques currently practiced, and use the method to evaluate Earthquake Emergency Micro Response System (EEMRS) [27].The contents of this paper are organized as follows: The introduction is presented in section 1, followed by the methodology in section 2. Section 3 presents results and section 4 presents discussions followed by the conclusions in section 5.

2. Methodology

Here, a general analytical method is developed, consisting of three major components, which are input, system, and output. Fig. 1 shows the flow chart of analytical model.

2.1. Input

There are two inputs in this model, the scenario input and system input. In the current paper, as mentioned earlier, the search and rescue (SAR) operations has considered in the context of Japan, where the front-line activities are carried out by firestation and firefighters. Thus the system input comprises of affected areas, number of trapped victims at each affected area, the total number of the fire station and firefighters (i.e., first responders) for the affected region and travel time from the fire station to affected area. The system input refers to all the possible techniques accessible to incident command center for gathering information on damage, trapped victims and the location. Mathematically, it could be expressed as:

$$\text{Initial situation analysis} \propto f(I) \tag{1}$$

$$I = \{\mathrm{i_T}, \text{information index attributing to the victim's condition and location}\} \tag{2}$$

$$T :\longrightarrow \text{set of all techniques to obtain information on the initial situation of the disaster affected areas} \tag{3}$$

In the current study, T is comprised of smart watch, remote sensing, unmanned arial vehicles, emergency calls, social media, reconnaissance survey, and mass media.

$$i_T \subset \{i_{SW}(t), i_{RS}(t), i_{UAV}(t), i_{EC}(t), i_{SM}(t), i_{FRS}(t), i_{MM}(t)\} \tag{4}$$

Where *t* is the time. Each of these indices represent the ratio of information of the victims obtained at the incident command center and the actual number of victims. All the indices vary over time depending on their characteristics of delivering information. We postulated general patterns of each

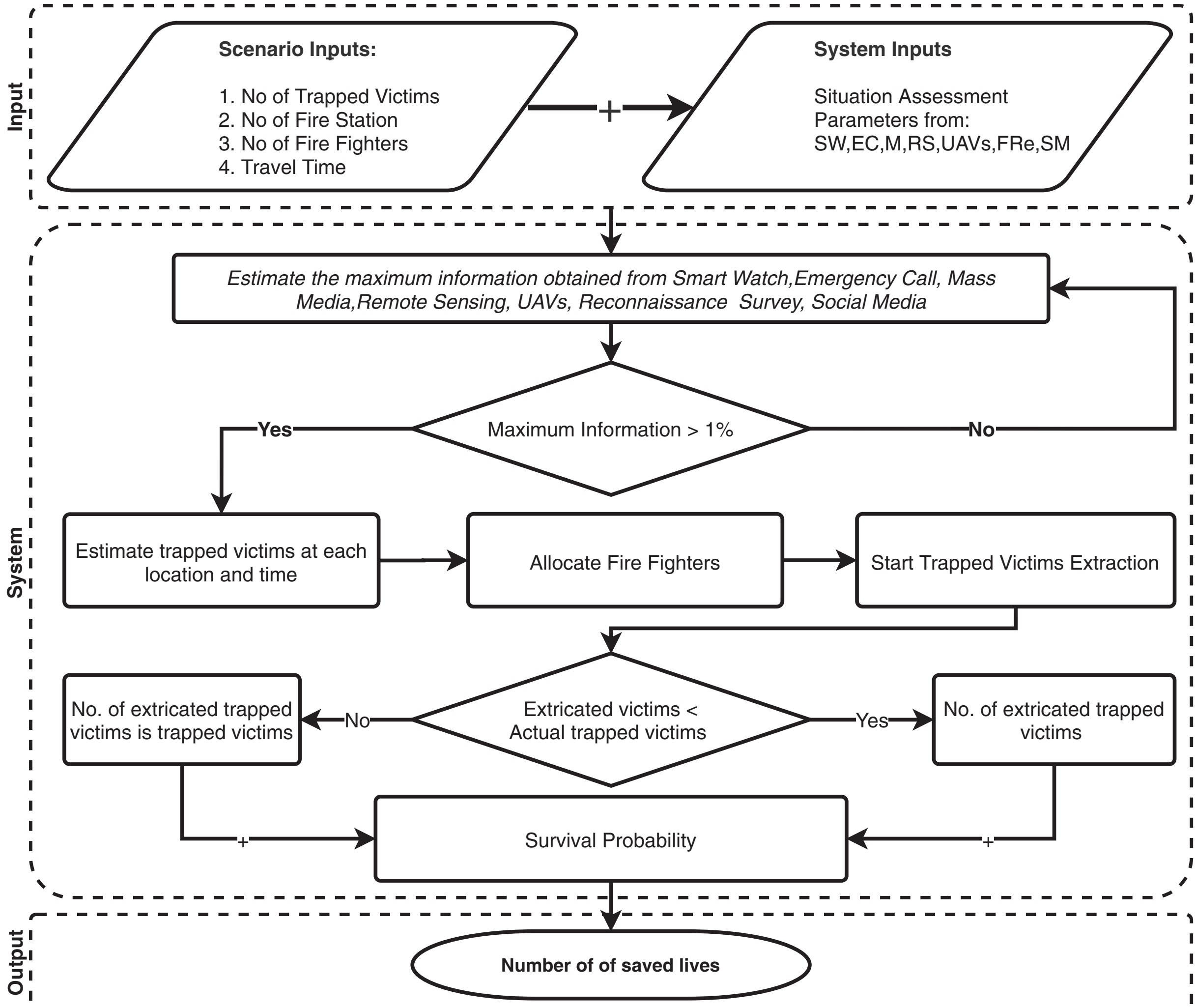


Fig. 1. Flow chart of the proposed analytical model to evaluate post-earthquake initial situation assessment method with popular techniques used at the incident command center.

initial situation assessment technique based on the proposed formulations as shown in Fig. 2. In other words, information index (which is the availability of post-earthquake damage and trapped victims information's to incident commanders) from the affected area to the incident command centre (ICC). The upper bound means that the information index is very high with time (usually 0 to 72 hrs) which represents emergency institute sound preparedness to gather post-earthquake damage and trapped victims information's from affected area. The lower bounds mean the information index is very slow with time (usually 0 to 72 hrs) which represents emergency institute poor preparedness. Fig. 2 represents the upper bound and lower bound respectively to analyse initial situation after the earthquake. However, we assumed that lower bound will reach maximum information index (1) with time, however in certain circumstances it may not able to reach maximum information index. For that case user can define the maximum information index value for lower bound based on their experience.

Summary of parameters used in the formulations are tabulated and shown in A.3 and further details on each of these techniques are explained hereafter.

i_{SW}, represents the **information index of smart watch**, and is given in Eq. (5).

$$i_{SW}(t) = \begin{cases} 0, & t < t_c \\ bp \times P_{sw}, & t \geq t_c \end{cases} \tag{5}$$

t_c is the minimum required time to process the information by this proposed technique, bp is buffer parameter, and P_{sw} is a percentage of smart watch users in the affected area varying from 0 to 100. t_c is chosen according to the medical experts, and detailed analysis is done in the previous paper [27], who said that a stable measurement would be obtained after a duration of about 15–20 min. With additional processing time and some consideration to factor of safety, it has been chosen to be 1 hr. Buffer parameter, bp, varying from 1 to 2, is introduced with a purpose that even if the percentage of smart watch user is less, it is possible to identify a higher number of trapped victims by utilizing the pre-existing seismic risk of the location of interest. For example, by promoting the use of smartwatch among vulnerable communities, information from smart watch can cover more than 10% of trapped victims, even when only 10% of the people use smartwatches. This results due to identification of trapped victims location where other people (not using smartwatches) might also be expected to be trapped.

i_{RS}, represents the **information index of remote sensing** and is shown in Eq. (6).

$$i_{RS}(t) = \begin{cases} 0, & t < t_c \\ AC \times Acr, & t \geq t_c \end{cases} \tag{6}$$

This equation is proposed with an assumption that remote sensing would follow a stair-step type pattern to provide damage extent of the

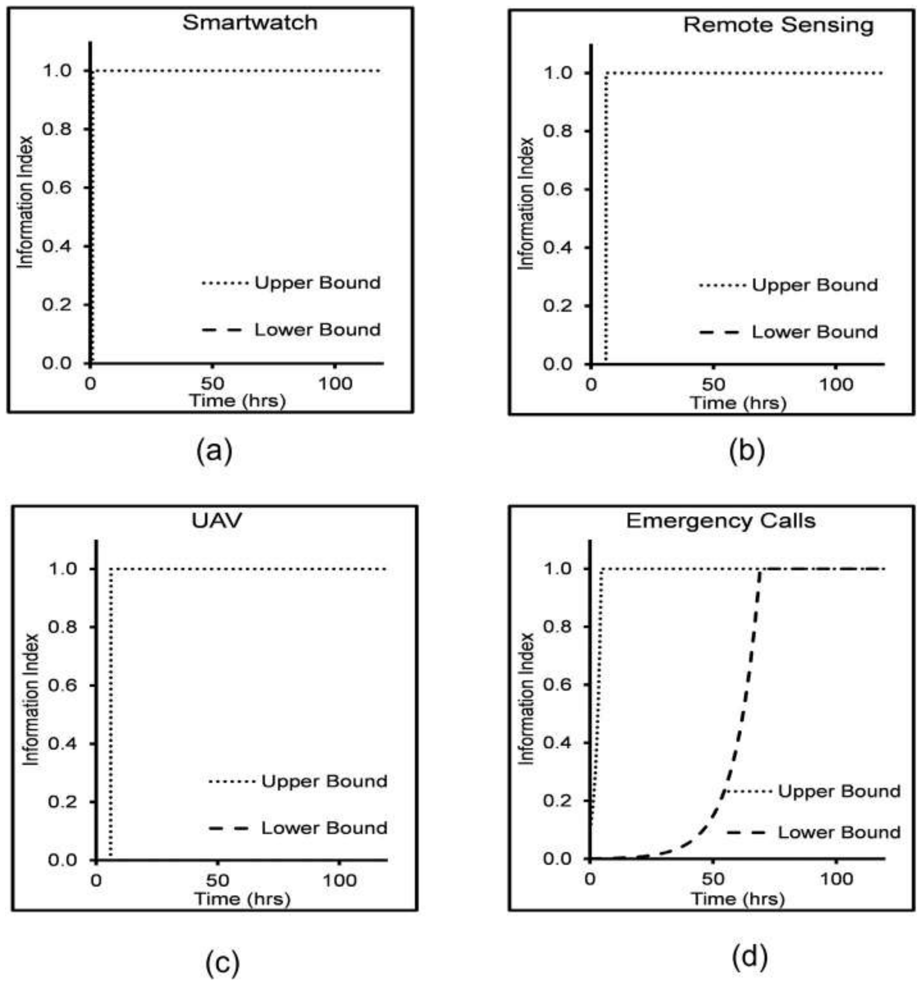


Fig. 2. Post-earthquake damage and trapped victims information providing patterns of different post-earthquake initial situation assessment techniques in the form of information time-series.

affected area and that the number of steps would depend on the extent of the affected area, image availability and processing time. For instance, if information with whole area coverage and reasonable accuracy is obtained after 12 hrs then it will be of one step stair-step type pattern. If information with 50% area coverage and reasonable accuracy is obtained after 12 hrs and remaining area coverage is obtained after 24 hrs then it will be of multi steps stair-step type pattern. t_c is the minimum required time needed to give damage assessment by remote sensing and correlate to the expected trapped victims, *AC* is the area coverage, and *Acr* is accuracy or data reliability. In the current research, it is assumed, based on our observation and experts opinion, that t_c will be at least 6 hrs and maximum 72 hrs, which is dependent on the extent of disaster-affected area, the percentage of damage and capacity for post-earthquake remote sensing data processing, and cloud-free image availability.

i_{UAV}, represents the **information index of Unmanned Aerial Vehicles** and provides information to incident command centre similar to remote sensing, it is also assumed that UAVs will follow stair-step type pattern and is shown in Eq. (7).

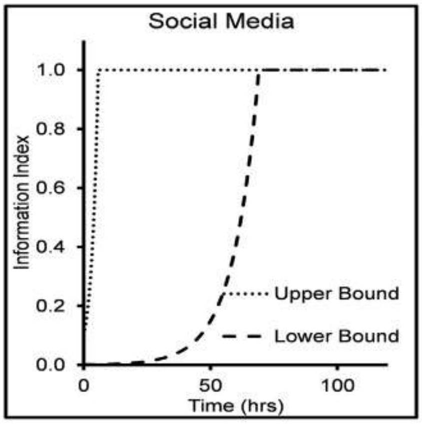
$$i_{UAV}(t) = \begin{cases} 0, & t < t_c \\ AC \times Acr, & t \geq t_c \end{cases} \tag{7}$$

Where t_c is the minimum required time needed for damage assessment and assimilation by UAVs, *AC* is the area coverage in percentage of the total built area, and *Acr* is accuracy or data reliability. In the past, Micro-copter and eBee type platform (Flight Height: 70 m and 150 m respectively) were used which required 13 and 17 min of flight time to acquire 0.15 and 1.0 km^2 respectively [15]. However, in this research, it is assumed that t_c will be at least 6 hrs and a maximum of 48 hrs considering the extent of disaster-affected area, the percentage of damage and institution preparedness for post-earthquake UAVs survey.

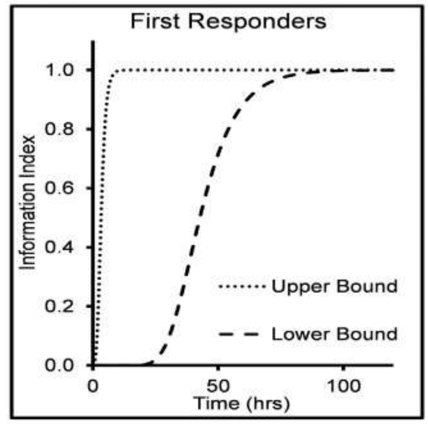
i_{EC}, represents the **information from emergency call** and is shown in Eq. (8). In Japan, one of the main sources of information collection about damage and causalities immediately after the earthquake is the emergency calls (dialled at 119). Thus, Eq. (8) is developed based on the Kobe earthquake emergency call data received by Kobe Fire Department during emergency period (Fig. 3) and the assumption that, if information providers are the public then it will follow exponential type pattern.

$$i_{EC}(t) = a \times e^{(b \times t)} \tag{8}$$

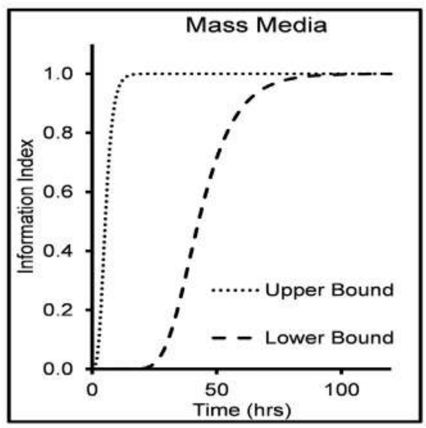
Where, a = Initial value which depends on congestion of line or capacity of emergency service center to tackle huge number of incoming calls,



(e)



(f)



(g)

Fig. 2 (*continued*).

and b, depends on emergency call receiving rate/ information rate (total required time to cover the whole affected area).

i_{SM}, represents the **information from social media** and the corresponding equation is shown in Eq. (9). As the information providers for social media are the public, it will also follow surge of data over a period of time.

$$i_{SM}(t) = a \times e^{(t \times b)} \tag{9}$$

Where a = Initial value which depends on data mining of social media apps for affected people, and b depends on information rate (time required to cover the affected area).

i_{FRS}, represents the **information from fast reconnaissance survey**, is shown in Eq. (10). It follows S-type pattern to transmit trapped victims' location and damage level of the affected area to the emergency manager. As the initial first responders (police, fire fighter, and local government officers) need to go the affected area, it will take some time to obtain the information. Similarly, at the end of the survey, the information attainment rate will gradually become zero.

$$i_{FRS}(t) = 1 + e^{(-t \times a)^{-b}} \tag{10}$$

Where, a = slope steepness (depends on total required time to cover the whole affected area) and b depends on beginning time for data transferring to emergency manager or local authorities.

i_{MM}, represents the **information from mass media** and the equation is shown in Eq. (11). The electronic media will also follow ‘S’ type pattern to transmit trapped victims' location and damage level of the affected area to the public as well as to the emergency manager and policy makers.

$$i_{MM} = 1 + e^{(-t \times a)^{-b}} \tag{11}$$

Where, a depends on total required time to cover the whole affected area and b depends on the beginning time for media forecast.

It must be noted that information provision patterns of all methods have been justified only based on observations and experts concern, need to be validated by real data if possible. Hypothetical equations only considered the normal distribution, and may also need to include more parameters in equation to consider the roughness.

2.2. System

The first step of the system is to estimate maximum information at each time. The following equation has been proposed to calculate the maximum information at each time.

$$I_{MAX} = max\,\|(i_{SW} \times w1, i_{RS} \times w2, i_{UAV} \times w2, i_{EC} \times w1, i_{SM} \times w2, i_{FRS} \times w1)\| \tag{12}$$

I_{MAX} is the estimate of maximum information of the initial situation assessment and the weights primarily govern the dependency of these information at the incident command center. In this study they have been chosen as, $w1 = 1.0$ and $w2 = 0.5$. This decision is attributed to the

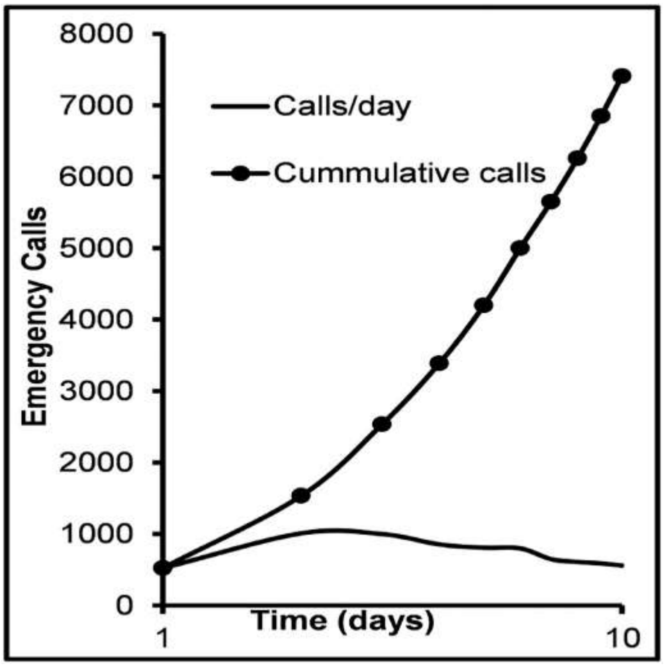


Fig. 3. The number of emergency call received history by Kobe firefighters during Kobe earthquake 1995 (Source: [3]).

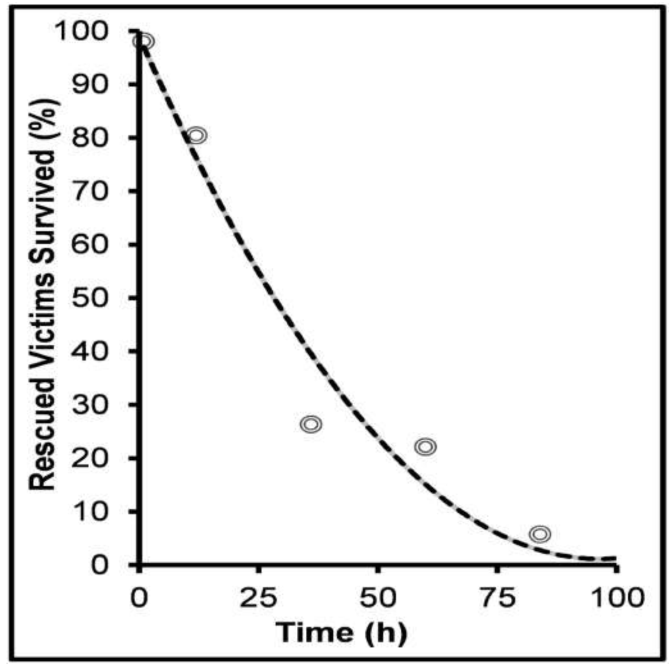


Fig. 4. Regression of survival probability of trapped victim's based on Kobe earthquake 1995.

Kobe earthquake 1995, where besides emergency call and field reconnaissance survey, the influence of remaining techniques for allocating first responders were not clear which is why 50% weight has been assumed during estimation total or maximum information each time. The next step of the system or process is to calculate the estimated trapped victims at each location and time.

$$n_{esTV} = n_{TV} \times I_{MAX} \tag{13}$$

nesTV is the number of estimated trapped victims, n_{TV} is the actual number of trapped victims. The third step is to allocate resources unit, n_{ARU} is the resource units to be allocated for SAR operations represented by fire stations shown in Eq. (14).

$$n_{ARU} = \frac{(n_{esTV}[i] - n_{exTV}[i]) \times \sum_i n_{FS} \times I_{MAX}}{\sum_i (n_{esTV}[i] - n_{exTV}[i])}; i^{th} \text{ location} \tag{14}$$

n_{exTV} is the number of extricated trapped victims, n_{FS} is the number of fire station (number of resource units). The fourth step of the system is to extricate trapped victims as given in Eq. (15).

$$n_{exTV}[i] = \frac{n_{ARU} \times m_{FF} \times dt}{t_{EMH}} \tag{15}$$

m_{FF} = Number of fire fighters involved to extraction trapped victims at each fire station, $dt = time[i+1] - time[i]$, t_{EMH} is the number of hours required by one firefighter to extricate one victim. The final step of system is to use survival probability (P_S) given in Eq. (17), which is established based on Kobe earthquake 1995 fire fighter data the Eq. (16) to estimate the number of saved lives at each time (Fig. 4).

$$P_S(\%) = 0.0105 \times t^2 - 1.976 \times t + 97.058 \tag{16}$$

Table 1
Summary of Kobe earthquake trapped victims and firefighter capacity used as input for the current study (Source [5]).

Area ID	Area Name	No. of trapped victims	No. of fire stations	Travel time (h)
1	Nishi	2	3	1
2	Tarumizu	2	3	1
3	Suijo	3	2	1
4	Kita	6	4	1
5	Suma	189	3	2
6	Fukiai and Ikuta	197	4	2
7	Hyuogo	252	2	3
8	Nagata	390	3	3
9	Nada	417	2	4
10	Higashi Nada	428	3	4

2.3. Output

The final output of the proposed model is number of saved lives (n_{SL})at each location and each time shown in Eq. (17).

$$n_{SL}[i] = n_{exTV}[i] \times P_S \tag{17}$$

2.4. Case study for verification

In this study, the scenario input is based on the Kobe fire fighter activities during Kobe earthquake 1995. In total, 1886 trapped victims were rescued by Kobe fire fighters, among them 735 victims were alive. Table 1 shows Kobe scenario inputs by Kobe firefighters. There were 29 fire stations in Kobe city and total 1298 full time firefighters. Travel time from fire station to affected area have been considered from 1 to 4 hrs with the assumption that less severely affected area took less time and more severely affected area took more time. The extrication man hours (man hours needed to extricate one trapped victim) have been assumed to be 8 man hours to extricate one victims for the first 12 hrs from the disaster, 12 man hours from 12 to 24 hrs after the disaster, 30 man hours from 24 to 48 hrs after the disaster, 35 man hours from 48 to 72 hrs after the disaster, 61 man hours from 72 to 96 hrs and 119 man hours from 96 to 120 hrs after the disaster based on trapped victims extricated by Kobe firefighters [noa, 1995]. The information index (which is the availability of post-earthquake damage and trapped victim's information to incident commanders) from the affected area to the incident command centre (ICC) have been considered only from emergency call and fast reconnaissance survey as the influence of remaining tools and techniques for allocating first responders are not clear in 1995 Kobe Earthquake.

2.5. Evaluation of EEMRS

The analysis is divided into two categories depending on considering depending on injury dependent extrication, which are case-1: quantitative evaluation without considering injury severity where we have used same scenario input as case study for verification and case-2: quantitative evaluation with considering injury severity. Usually, first responders extricate trapped victims using damage severity, however, with realtime health parameters it is possible to conduct extrication based on injury level which can enhance the number of saved lives, we have considered case-2. In case-2 the injury composition ratio in Kobe City in the Kobe earthquake 1995 based on Ohta et al., 2001 have been used. These are given in Table 2.

3. Results

The output of the results shown in this section starts with the verification of the analytical model developed in this study. Followed by the quantitative evaluation of the EEMRS by time series of number of saved lives over varying the percentage of people wearing smart watches. Further analysis of evaluation is done to evaluate the influences of smart watches over other initial situation assessment techniques with and without injury level considerations.

3.1. Verification results

Fig. 5 shows the number of saved lives at actual (Kobe earthquake 1995) case and output of analytical model. In the actual case, Kobe firefighters rescued 735 alive victims (38.97%) [5], while the model predicts 744 alive victims (39.44%). The performance of the model to simulate the realistic scenario is acceptable as the difference between actual and model is only 0.47%.

3.2. Evaluation results

Fig. 6 represents the effect of smart watch without considering injury level during trapped victims extrication. In terms of number the maximum effect is up to 345 person for particular Kobe case without considering any other constrain except initial situation assessment. However, in terms of percentage the effect is up to 19%. From the Fig. 6(b) shown on the right, it is clearly visible that with increase of smart watch use, the information percentage and the percentage of saved life increases exponentially.

Table 2
Composition ratio by level of injury and Life-span-characteristics-function for the Kobe earthquake 1995 (Source: [42]).

Injury level	Composition ratio in Kobe city in the Great Hanshin-Awaji Earthquake	Life-span-characteristics-function[t = time(h)]
Death/Dying	2%	$e^{[-(t/0.092)^{3.71}]}$
Serious injury	11%	$e^{[-(t/3.324)^{3.71}]}$
Medium injury	23%	$e^{[-(t/12.300)^{3.71}]}$
Slight injury	30%	$e^{[-(t/26.590)^{3.71}]}$
Uninjured	34%	$e^{[-(t/66.480)^{3.71}]}$

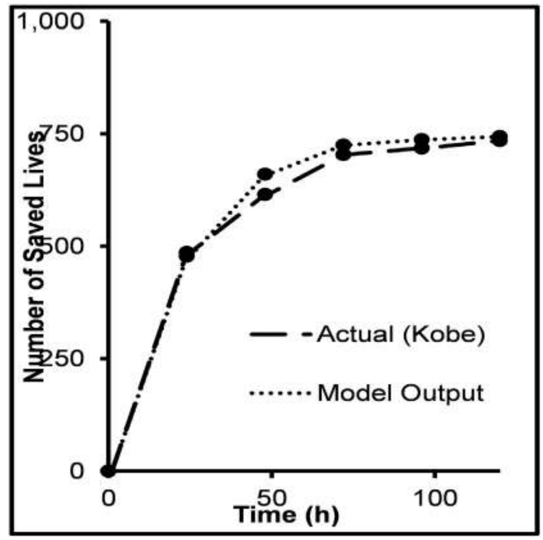


Fig. 5. Verification of analytical model results by comparing it with the number of saved lives in the case of Kobe earthquake.

The result obtained from the primary comparison between without and with smart watch (assumed usage of 50%) at different injury level is shown in Fig. 7(a) shown on the left. It can be seen from the graph that the cases of serious injury and uninjured trapped victims show minimal difference between outcomes of with or without smart watch: 5% in case of serious injury and only 1% for uninjured. However, there was a significant difference in case of medium injury trapped victims, where the percentage of saved people can be 18% higher if smartwatch is being used. The Fig. 7(b) shown on the right, illustrates percentage of saved lives with considering injury level at different smartwatch usage levels. Further analysis showed that percentage of saved lived increase up to 5% as compared to the case of without considering injury level.

4. Discussions

From the results section it is clearly visible that with increase in smart watches usage among the population and subsequent increase in information availability, the percentage of saved lives can increase almost exponentially. This is because the resource allocation in this study is assumed to be proportional to the information index. Extrication of trapped victims by considering injury level is done with an assumption that the fire fighters will first extricate the medium, slight and uninjured trapped victims and after which they will extricate dead or seriously injury trapped victims. These results can suggest that incorporating the data disseminated through smart watches can be invaluable to the emergency experts to carry out effective SAR operations. It is to be noted once again that this approach should be used to compliment the existing techniques of initial situation assessment and not as a replacement of current techniques.

The analytical model developed in this study acts as a base model to analyse the initial situation obtained from different sources and, to the authors knowledge, is possibly the first attempt of quantifying information assimilation at the incident command center. This model can be used to study the strengths and weaknesses of different initial situation analysis techniques. The techniques in this study are formulated as hypothetical equations by pattern estimation as there is not enough data to come up with regressive equations. The trends for information dissemination in various techniques considered are based on experiences, observations and expert opinions, but randomness in this information dissemination is not considered. The parameters can be assessed more accurately with different indirect methods and by having randomness and complex interlaced formulations of multiple methods.

As smart watches are able to give real time heart rate of trapped victims, observing this can allow one to distinguish death or seriously injured

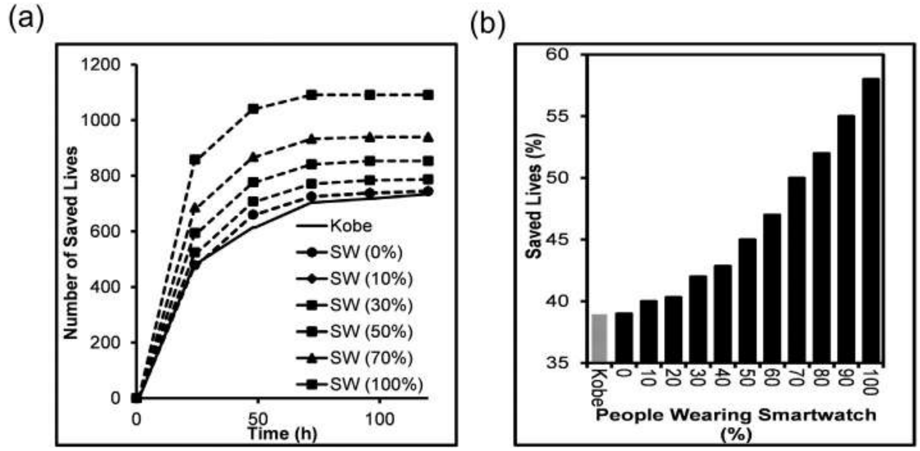


Fig. 6. Evaluation results showing the saved lives estimated from the analytical model.

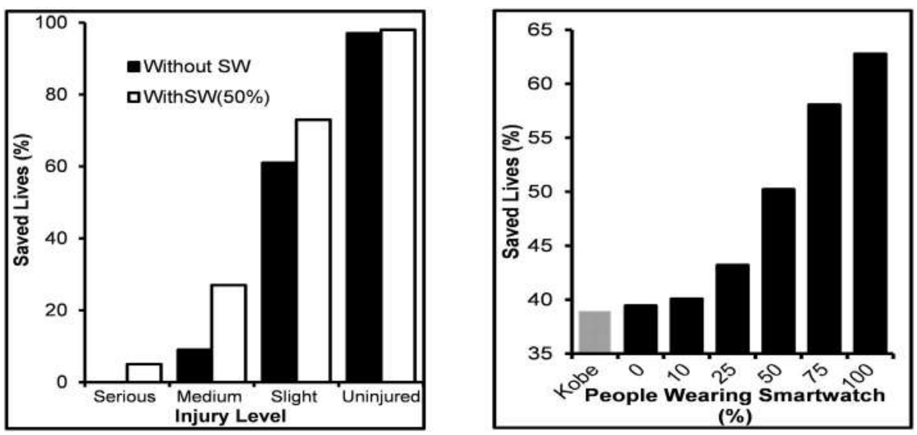


Fig. 7. Evaluation results showing the saved lives estimated from the analytical model considering injury based extrication.

trapped victims from medium, slight and uninjured trapped victims. This study mainly focused on using the existing smart watches to dissipate the data through the application developed in the first paper. However, the technological advancements of wearable devices incorporating sensors to extract blood pressure and other health parameters can lead to more accurate information attainment of victims for effective search and rescue operations.

5. Conclusions

In this research, a simple analytical model has been developed to help the earthquake emergency managers which included different methods for post-earthquake initial situation assessment. This analytical method was verified with Kobe earthquake firefighter activities and extended to evaluate the impact of EEMRS over other systems to get information on initial situation. The analytical results showed that increase in use of smart watch by trapped victims with the proposed application would save more lives as the uncertainty of location and victim condition is reduced significantly, aiding the emergency SAR operations. While this study considered the rapid information availability, our future considerations will include randomness in the information dissemination of various post-earthquake initial situation assessment techniques, and resource constrains along with information availability within the proposed analytical model.

Declaration of Competing Interest

None.

Appendix A. Parameters and definitions

Table A.3
Model parameters.

Module	Sub System	Parameters	Descriptions	Limits		Remarks
				L	U	
Initial Situation Analysis	Smart-watch	t_c	Process Time	1	1	Proposed
		b_p	Buffer Parameters	1	2	
		P_{sw}	Percentage of SW	0	1	
	Remote Sensing	t_c	Process Time	1	72	With time AC and Acc will increase
		AC	Area Coverage	0	1	
		Acc	Accuracy or reliability	0	1	
	UAVs	t_c	Process Time	1	48	
		AC	Area Coverage	0	1	
		Acc	Accuracy or reliability	0	1	
	Emergency Call	a	Initial value which depends congestions of line	0.001	0.1	Higher value represents robustness
		b	Depends on emergency call receiving rate/ information rate (total require time to cover whole affected area)	0.1	0.5	
	Mass Media	a	Depends on total require time to cover whole affected area	0.1	0.5	
		b	Depends on the beginning time of media forecast	−50	−10	
	Field Reconnaissance	a	Slope steepness (depends on total time to cover whole affected area)	0.1	0.8	
		b	Depend on the beginning time of data sending	−50	−10	
	Social Media	a	Initial value which depends on data mining of social media apps for affected people	0.001	0.1	
		b	Information rate (depends on total time to cover whole affected area)	0.1	0.4	
Resources Allocation	Situation Analysis	I_{MAX}	Maximum Infomation available at eatch time	0	1	*Kobe
		Info Threshold	Minimum information require to assign resources	0	1	
	Estimated TV Resources	n_{esTV}	Estimated Trapped Victims	0	T_v	
		n_{FS}	Number of fire station (number of resource units)	0	29	
		m_{FF}	No of firefighters involved to extraction trapped victims at each fire station	0	50	
Victims Extricate and saved lives	Travel Time	Ta	Require time from ICS to affected area	0	12	
	Extricate Man Hours	t_{EMH}	Man hours need to extricate each victims	1	120	
	Survival Probability (%	P_s	Number of saved lives at each hour	0	1	

References

[1] Company Info Facebook Newsroom. Retrieved July 2, 2018, from https://newsroom.fb.com/company-info/.
[2] Copernicus Emergency Management Service - Mapping. In Copernicus EMS - Mapping. Retrieved July 2, 2018, from http://emergency.copernicus.eu/mapping/.
[3] Fire situation in the Great Hanshin Awaji Earthquake Kobe City Area Kobe City fire department edited, Heisei era; 1996.
[4] Twitter: number of active users 2010-2018. In Statista. Retrieved July 8, 2018, from https://www.statista.com/statistics/282087/number-of-monthly-active-twitter-users/.
[5] Fire Fighter Activities in 1995 Great Hanshin Awaji Earthquake; 1995 Kobeshi Shouboukyoku.
[6] UNOSAT Rapid Mapping Service; 2014 Retrieved July 2, 2018. from https://unitar.org/unosat/unosat-rapid-mapping-service.
[7] Abbasi, A., Hossain, L., Hamra, J., and Owen, C. (2010). Social networks perspective of firefighters' adaptive behaviour and coordination among them. In Green Computing and Communications (GreenCom), 2010 IEEE/ACM Int'l conference on & int'l conference on cyber, physical and social computing (CPSCom), pages 819–824. [IEEE].
[8] Al-Khudhairy D, Caravaggi I, Giada S. Structural damage assessments from Ikonos data using change detection, object-oriented segmentation, and classification techniques. Photogramm Eng Remote Sens. 2005;71(7):825–37.
[9] Alexander D. Towards the development of a standard in emergency planning. Disaster Preven Manag. 2005;14(2):158–75.
[10] Batho S, Williams G, Russell L. Crisis management to controlled recovery: the emergency planning response to the bombing of Manchester city Centre. Disasters. 1999; 23(3):217–33.
[11] Becker JS, Paton D, Johnston DM, Ronan KR, McClure J. The role of prior experience in informing and motivating earthquake preparedness. Int J Dis Risk Reduction. 2017;22: 179–93.
[12] Behnam B. Post-earthquake fire analysis in urban structures: Risk management strategies. CRC Press; 2017.
[13] Bhandari RK. Disaster education and management: A joyride for students, teachers and disaster managers; 2013 [Springer Science & Business Media].
[14] Bird D, Ling M, Haynes K, others. Flooding Facebook-the use of social media during the Queensland and Victorian floods. Aust J Emerg Manag. 2012;27(1):27.
[15] Boccardo P, Chiabrando F, Dutto F, Tonolo FG, Lingua A. UAV deployment exercise for mapping purposes: evaluation of emergency response applications. Sensors. 2015;15(7): 15717–37.
[16] Carlson, J. D., Mittek, M., Parkison, S. A., Sathler, P., Bayne, D., Psota, E. T., PÃ©rez, L. C., and Bonasera, S. J. (2014). Smart watch RSSI localization and refinement for behavioral classification using laser-SLAM for mapping and fingerprinting. In Engineering in Medicine and Biology Society (EMBC), 2014 36th annual international conference of the IEEE, pages 2173–2176. [IEEE].
[17] Chen L, Miller-Hooks E. Optimal team deployment in urban search and rescue. Transp Res Part B. 2012;46(8):984–99.
[18] Chiroiu L, Adams B, Saito K. Advanced techniques in modelling, response and recovery. Assessing and managing earthquake risk. Springer; 2008. p. 427–48.
[19] Chiu W-T, Arnold J, Shih Y-T, Hsiung K-H, Chi H-Y, Chiu C-H, et al. A survey of international urban search-and-rescue teams following the Ji Ji earthquake. Disasters. 2002;26 (1):85–94.
[20] Chiu Y-Y, Omura H, Chen H-E, Chen S-C. Indicators for post-disaster search and rescue efficiency developed using progressive death tolls. Sustainability. 2020;12(19):8262.
[21] Dave R. Role of Media in Disaster management-Dr Dave-2; 2020 https://www.academia.edu/4566703/Role_of_Media_in_Disaster_management.
[22] Dell'Acqua F, Gamba P. Remote sensing and earthquake damage assessment: experiences, limits, and perspectives. Proc IEEE. 2012;100(10):2876–90.
[23] Eguchi RT, Goltz JD, Seligson HA, Flores PJ, Blais NC, Heaton TH, et al. Real-time loss estimation as an emergency response decision support system: the early post-earthquake damage assessment tool (epedat). Earthq Spectra. 1997;13(4):815–32.
[24] Fiedrich F, Gehbauer F, Rickers U. Optimized resource allocation for emergency response after earthquake disasters. Saf Sci. 2000;35(1):41–57.
[25] Ghosh S, Gosavi A. A semi-markov model for post-earthquake emergency response in a smart city. Control Theory Technol. 2017;15(1):13–25.
[26] Hoffmann J. Mapping damage during the bam (Iran) earthquake using interferometric coherence. Int J Remote Sens. 2007;28(6):1199–216.
[27] Hossain M, Gadagamma C, Bhattacharya Y, Numada M, Morimura N, Meguro K. Integration of smart watch and geographic information system (gis) to identify post-earthquake critical rescue area part. i. development of the system. Progress Disaster Sci. 2020;7:100116.
[28] Huang C-M, Chan E, Hyder AA. Web 2.0 and internet social networking: a new tool for disaster management?-lessons from Taiwan. BMC Med Inform Decis Mak. 2010;10 (1):57.

[29] Jovanov E. Preliminary analysis of the use of smartwatches for longitudinal health monitoring. Engineering in medicine and biology society (EMBC), 2015 37th Annual International Conference of the IEEE, pages 865–868; 2015 [IEEE].
[30] Joyce KE, Wright KC, Samsonov SV, Ambrosia VG. Remote sensing and the disaster management cycle. Adv Geosci Remote Sens. 2009;48:7.
[31] Kamdar MR, Wu MJ. PRISM: a data-driven platform for monitoring mental health. Biocomputing 2016: Proceedings of the Pacific symposium. World Scientific; 2016. p. 333–44.
[32] Kavanaugh AL, Fox EA, Sheetz SD, Yang S, Li LT, Shoemaker DJ, et al. Social media use by government: from the routine to the critical. Govern Inform Q. 2012;29(4):480–91.
[33] Kim JW, Lim JH, Moon SM, Jang B. Collecting health lifelog data from smartwatch users in a privacy-preserving manner. IEEE Transac Consum Electron. 2019;65(3):369–78.
[34] Lewis S. Remote sensing for natural disasters: Facts and figures; 2009.
[35] Lockman J, Fisher RS, Olson DM. Detection of seizure-like movements using a wrist accelerometer. Epilepsy Behav. 2011;20(4):638–41.
[36] Lu Y, Xu D, Wang Q, Xu J. Multi-stakeholder collaboration in community post-disaster reconstruction: case study from the longmen Shan fault area in China. Environ Hazards. 2018;17(2):85–106.
[37] Lutze R, Waldhör K. A smartwatch software architecture for health hazard handling for elderly people. In 2015 International conference on healthcare informatics; 2015. p. 356–61.
[38] Mavroulis S, Andreadakis E, Spyrou N-I, Antoniou V, Skourtsos E, Papadimitriou P, et al. Uav and gis based rapid earthquake-induced building damage assessment and methodology for ems-98 isoseismal map drawing: the june 12, 2017 mw 6.3 lesvos (northeastern aegean, Greece) earthquake. Int J Disaster Risk Reduction. 2019;37:101169.
[39] Meissner A, Luckenbach T, Risse T, Kirste T, Kirchner H. Design challenges for an integrated disaster management communication and information system. The First IEEE workshop on disaster recovery networks (DIREN 2002), 24. ; 2002. p. 1–7.
[40] Mortazavi B, Nemati E, VanderWall K, Flores-Rodriguez HG, Cai JYJ, Lucier J, et al. Can smartwatches replace smartphones for posture tracking? Sensors. 2015;15(10): 26783–800.
[41] Nojima N, Sugito M. Bayes decision procedure model for post-earthquake emergency response. Proc. of the 5th US Conference on Lifeline Earthquake Engineering, TCLEE/ ASCE Monograph, number 16; 1999. p. 217–26.
[42] Ohta Y, Koyama M, Watoh Y. An attempt of evaluating life span characteristics after an earthquake in case of 1995 hyogoken nanbu earthquake. Technical report Research Institute of Earthquake Science; 2001.
[43] Pan S, Li M. Construction of earthquake rescue model based on hierarchical voronoi diagram. Mathematical Problems in Engineering, 2020; 2020.
[44] Paton D, Johnston D. Disaster resilience: An integrated approach. Charles C Thomas Publisher; 2017.
[45] Pradhan D, Sujatmiko N. Can smartwatch help users save time by making processes efficient and easier? Technical report Universitas Osloensis, Department of Informatics; 2014.
[46] Qie Z, Rong L. An integrated relative risk assessment model for urban disaster loss in view of disaster system theory. Nat Hazards. 2017;88(1):165–90.
[47] UNISDR. Terminology on disaster risk reduction. Bangkok; 2009.
[48] Reeder B, David A. Health at hand: a systematic review of smart watch uses for health and wellness. J Biomed Inform. 2016;63:269–76.
[49] Reilly P, Atanasova D. A report on the role of the media in the information flows that emerge during crisis situations; 2016.
[50] Saito K, Spence R. Rapid damage mapping using post-earthquake satellite images. Geoscience and remote sensing symposium, 2004. IGARSS'04. proceedings. 2004 IEEE international, 4. ; 2004. p. 2272–5 [IEEE].
[51] Saito K, Spence RJ, Going C, Markus M. Using high-resolution satellite images for post-earthquake building damage assessment: a study following the 26 January 2001 Gujarat earthquake. Earthq Spectra. 2004;20(1):145–69.
[52] Samui P, Kim D, Ghosh C. Integrating disaster science and management: Global case studies in mitigation and recovery. Elsevier; 2018.
[53] Sarcevic, A., Palen, L., White, J., Starbird, K., Bagdouri, M., and Anderson, K. (2012). Beacons of hope in decentralized coordination: Learning from on-the-ground medical twitterers during the 2010 Haiti earthquake. In Proceedings of the ACM 2012 conference on computer supported cooperative work, pages 47–56. ACM.
[54] Scanlon J. Research about the mass media and disaster: never (well hardly ever) the twain shall meet. Journal Theory Pract. 2011:233–69.
[55] Simon T, Goldberg A, Adini B. Socializing in emergencies—a review of the use of social media in emergency situations. Int J Inform Manag. 2015;35(5):609–19.
[56] Struble C. Benefits of using a smartwatch; 2013.
[57] Takemoto S, Shibuya N, Kuek SC, Keeley AR, Yarina L. Information and communication technology for disaster risk management in Japan. Technical Report. The World Bank; 2019.
[58] Tong X, Hong Z, Liu S, Zhang X, Xie H, Li Z, et al. Building-damage detection using pre- and post-seismic high-resolution satellite stereo imagery: a case study of the may 2008 Wenchuan earthquake. ISPRS J Photogramm Remote Sens. 2012;68:13–27.
[59] Vidal F, Feriche M, Ontiveros A. Basic techniques for quick and rapid postearthquake assessments of building safety. 8th international workshop on seismic microzoning and risk reduction. Almeria: Spain; 2009.
[60] Vu T, Matsuoka M, Yamazaki F. Towards an object-based detection of earthquake damaged buildings. Proceedings of international workshop on disaster monitoring and assessment through images. International Society for Photogrammetry and Remote Sensing, CD-ROM; 2005 (5p).
[61] Wegscheider S, Schneiderhan T, Mager A, Zwenzner H, Post J, Strunz G. Rapid mapping in support of emergency response after earthquake events. Nat Hazards. 2013;68(1): 181–95.
[62] Whalen J, Zimmerman DH, Whalen MR. When words fail: a single case analysis. Soc Probl. 1988;35(4):335–62.
[63] Wijaya R, Setijadi A, Mengko TL, Mengko RK. Heart rate data collecting using smart watch. System engineering and technology (ICSET), 2014 IEEE 4th international conference on, 4. ; 2014. p. 1–3 [IEEE].
[64] Xu J, Lu Y. Meta-synthesis pattern of post-disaster recovery and reconstruction: based on actual investigation on 2008 wenchuan earthquake. Nat Hazards. 2012;60(2):199–222.
[65] Yamazaki F, Yano Y, Matsuoka M. Visual damage interpretation of buildings in bam city using quickbird images following the 2003 bam, Iran, earthquake. Earthq Spectra. 2005; 21(S1):329–36.
[66] Zhang Y, Weng W, Huang Z. A scenario-based model for earthquake emergency management effectiveness evaluation. Technol Forecast Soc Change. 2018;128:197–207.