A Decision Analysis Framework for Emergency Notification

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Abstract

Notification is one of the major tasks for emergency responses. Quick and appropriate notification can save lives and significantly reduce damages. It is, however, challenging to make a right decision on notification. In this paper, we propose a decision analysis framework for emergency notification with what we term as "6 Wh-word Dimensions" (6WDs), namely, "when, where, who, why, what and how." Within each dimension, we present tasks, pose problems and establish criteria for arriving at decisions that are responsive, responsible and respectful. We also propose a decision support system (DSS) that can help sustain one's notification decision making within the 6WDs.

1. Introduction

In case of disasters, severe damages or losses of lives may happen without timely effective notification, which means to report an incident, its status, and instructions to the general public, organizations and individuals involved in emergency response. According to the literature [1-3], notification is an integral part of any emergency response systems (ERS) that plays a critical role in saving lives. In emergency, people must make quick decisions, often heavily relying on their past experiences in dealing with similar situations, on matters about life and death. They must also act quickly based on the information provided by notifications, where the adage "time is money" can be justly translated into "time is lives." Indeed, as has been pointed out [4, 5], a timely and accurate notification is as crucial as an emergency response which is prompt and coherent.

The importance of notification in ERS has been widely acknowledged. The effectiveness of notification has not, however, been fully studied and little is known to us about issues on: 1) what are the critical aspects of notification? 2) what are the important decision problems? 3) what are the criteria for decision making? 4) how can information technology help to support decision making in notification? The purpose of this paper is to provide a decision analysis framework for emergency notification that we have developed on the basis of our personal field experience in combination with our review of related literature on this issue. The paper is organized as follows. In Section 2, we first review some major publications, and present in Section 3 our proposed framework for emergency notification with what we term as "6 Wh-word Dimensions" (6WDs). In the subsequent sections, we will discuss decision tasks and decision support in these six dimensions, and offer conclusions of our study, respectively.

2. Literature Review

Emergency management, a field that has been established in order for people to learn how to act and cope with disasters during crises, mainly consists of four time-oriented stages, mitigation, preparedness, response, and recovery, with the first two being pre-emergency activities and the other two post-emergency activities [6, 7]. In respect with emergency responses, most researchers focus on the concept, process and components of emergency response systems and some have proposed emergency response frameworks [3, 6-8]. Yuan and Detlor (2005)

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have even worked out details by identifying eight major tasks of emergency response including monitoring, reporting, identification, notification, organization, operation, assessment, and investigation [3]. The functionality of the emergency response systems, especially the decision support function, has also been addressed [9-12]. Moreover, some researchers have examined the system design issues on the development [5, 13-16] and the integration of emergency response systems with knowledge management [12, 16-17]. A few practical Emergency Response Systems have been proposed, designed, and applied in some special domains such as the rural Emergency Medical Services system (EMS) [5], the Information Management System for Hurricane disasters (IMASH) [18], and Knowledge Management Systems for Hurricane Katrina Response [19]. This kind of initiatives and implementation has made it possible to achieve demonstrable public good in terms of lives saved [5]. It has to be pointed out, nevertheless, most of these studies have focused only on supporting specific foreseeable crises [10].

Coping with emergency, that is non-foreseeable crises, requires prompt decision making. Due to the nature of emergency (i.e., the presence of threat, danger, urgency and uncertainty), it is however difficult, and almost impossible, to rapidly develop adequate decision models and apply them efficiently in a real-world crisis. Decisions must be made by considering three constraints: limited time, limited information, and decision load [20]; and there is an increasingly greater need for decision-making skills in case of emergencies [21]. Therefore, decision making under emergency is an important research field. Vroom and Yetton have proposed a normative model [22] that describes corresponding relationships between three problem characteristics (quality, acceptance and urgency) and three actions (consult, act and delegate). Some specific emergency decision-making models have been analyzed, for instance, evacuation-decision making in a nuclear reactor leaking emergency [23], decision making during severe weather emergency [24]. Frameworks have been proposed for decision support systems [25], for information exchange between key decision makers [2], for identifying and removing false alerts that could flood information systems [26], and for public warning systems [27].

To summarize, the concept of notification has been explored for a long time [29, 48, 49]. It is widely recognized that notification is one critical component in emergency response. To assure emergency notification to be effective, critical issues about how to make notification clear and actionable and how to get confirmation from several information sources must be dealt with [27]. There is also a need of standardization for notification [28] and for incident notifications, for example, IEEE Standard for Common Incident Management Message Sets [29] and Alerting Protocol (CAP) [2, 30].

3. Decision Analysis Framework for Notification

Little consideration is given to decision analysis of notification in emergency and even less analysis is conducted of notification decision issues on what information should be notified and to whom plus a number of related issues as such as when and how, although Turoff (2004) has suggested that notification can be standardized and used for dispatch of resources. This paper goes some way toward remedying this within a framework we propose for decision analysis of notification in emergency responses. According to [31], decision analysis is defined as a formalization of common sense for decision problems, and our common sense tells us that it is too complex to be used for informal purposes. A more technical term for it is “a philosophy, articulated by a set of logical axioms, and a methodology and collection of systematic procedures, based upon these axioms, for responsibly analyzing the complexities inherent in decision problems” (p. 806) We formulate our project within the 6WDs that enables us to describe the tasks, problems and criteria for decision making of notification. The 6WDs, which is a formula for getting the “full” story on something, is widely used in various disciplines. For example, Bui & Tan used the six Ws’ to formulate a template as a structured approach to deal with communication, collaboration and cooperation needs in large-scale emergency responses [39]. In this study, we use the 6WDs as a framework for decision analysis of notification in emergency responses. Table 1 provides a detailed description of these dimensions, decision problems and associated corresponding cases for every dimension.

Table 1. The 6 Dimension for Decision Making in Notification

Dimension	Decision Problem	Case
When: The timing of notification	How to set up the timing threshold for notification?	It is a dilemma to determine the timing of notification due to the high level of uncertainty of disasters. On the one hand, an unnecessary alarm undermines public confidence and dilutes the impact of alerts, and it is too costly for an unwanted evacuation. For the past 56 years since 1948, 3/4 tsunami warnings issued have been false. On the other hand, a failure of notification about the true disaster may cause disastrous results. During the 2004 Indian Ocean earthquake, Sri Lanka's authorities were warned of a possible tsunami, but they tried to assess the seriousness of the tidal effect. This indecision delayed the notification and caused the loss of thousands of lives.
Where: The geographic range of notification	How to identify the disaster spreading pattern and impact area?	In February 2003, SARS erupted in Hong Kong and people who had close contact with patients were instantly infected. Within days or weeks, the disease spread rapidly world wide mainly through people who traveled by air planes. Without knowing the spreading pattern, it was difficult and very challenging to decide which areas would be impacted by this disaster, and who would be notified.
Who: The target receivers of notification	How to identify the parties to be notified?	During the 2004 Indian Ocean earthquake, the scientists in Hawaii were the first who had become aware that there would have an earthquake in Sri Lanka. Unfortunately, since there had been no international warning system put in place, they could not decide which authority to contact in order to notify the people at risk about the approaching tsunami in Sri Lanka. Consequently, millions of lives were lost - people were engulfed and gobbled up by the waves.
Why: The objectives or purposes of notification	How to balance multi-objectives of notification?	During the 2004 Indian Ocean earthquake, Thai officials were warned about a possible tsunami, but they didn't believe it would come and worried that a false alarm would damage its tourism industry. The conflicting multi-objectives in decision making caused a failure of notification. And the consequence was that the tsunami battered the tourist resorts of Thailand.
What: The components and content of notification	How to determine the right content of notification to meet its objectives?	During the Salt River flooding in Phoenix area in 1980, endangered residents were asked to evacuate, but the river crossings on their way to the location of the emergency shelter were closed. The instruction didn't tell receivers how to overcome this logistic problem, and this wrong decision on notification content confused residents and made them unable take the suggested protective actions.
How: The ways or methods of notification.	How to reach the targets in most effective and reliable ways?	During the Virginia Tech. massacre on April 16 morning, 2007, an email was sent to warn the students, but it failed to reach most of them at that moment. This wrong choice of notification medium contributed to a sizeable death toll.

WHEN

"When" refers to the timing of the notification to be delivered. Here the "when" dimension includes trigger, response speed, and repeating frequency. Notifications are triggered by emergency events for which a number of actions will be taken, for instance, new data entries, responses to earlier comments, occurrence or changes of some objects users are interested in [15]. Situational changes motivate notification delivery to receivers concerned, which may be however mobilized if the changes exceed the threshold of trigger. Response speed may be affected by the delay of decision making, which includes three types: handling delay, uncertainty delay, and unnecessary delay. While the handling delay occurs usually due to the approval procedure and the uncertainty delay results from lack of reliable information, the unnecessary delay unfortunately is often caused by human errors such as deliberate cover ups or negligence of one's duty and responsibility. Repeating frequency depends on the importance, the memorabilily, and the delivery reliability of notification [1].

It should also be pointed that a critical issue within the "When" dimension is to set up the timing threshold for notification. Timing decision depends on the urgency, the importance (loss severity), the reliability of information, the probability of occurrence, the approval procedure, and the possible mis-alarm aftermath [40-41].

WHERE

"Where" indicates the geographic range of notification. It includes the locations of possible victims and the geographic distribution of the resources for rescue. The geographic scope impacted by the disaster depends on the ways of spreading and the trend of the disaster. Different types of disasters have different ways of spreading patterns. For example, the one of SARS, that took place in 2003, is totally different from that of an earthquake [42]. Therefore, the geographic region is likely to be

classified according to possible impact levels and potential risks. Disasters of different nature and scope also need different resources for rescue. For most emergency cases, immediate response and rescue are needed. There might be resources available around the location of the disaster or they have to be brought in from afar. The choice of resources for rescue should be determined by the speed of acquisition and delivery instead of just by the distance between the locations of recourses and the locations of disasters.

Within the "Where" dimension, a critical decision problem is about how to identify and determine the disaster spreading pattern and impact area. This is a difficult decision because it depends on experts' knowledge, previous experience and their capability of making a prompt judgment that must be careful and sound. Another decision that should be made is the mapping from impact area to notification area, which might be broader than the former one. For instance, a notification may reach neighborhood areas calling for volunteers and their assistance and donations.

WHO

"Who" applies to people receive notification. Based on their roles and responsibilities, notification receivers can be categorized into three major groups: authorities, response teams, and potential victims. The authorities are those in charge of the Emergency Operation Center (EOC), police, various levels of government agent and jurisdictions, to name a few, who control the resources and make critical decisions in emergency response. They need to be first informed of critical decisions for emergency responses. Response teams are the people who execute the rescue or other supporting activities, such as policeman, firefighters, emergency medical technicians, volunteers etc. They need to be given whatever information is necessary in order for them to provide rescue support to victims. Potential victims are the individuals who are affected directly or indirectly by the disaster, and the seriousness of the risk they face. They need to be made aware of the at-risk status and advised to take appropriate and necessary actions to cope with the disaster.

To determine the "who" dimension, we need to deal with two critical decision problems: How to identify the parties to be notified? What is the priority of notification among them? The decision of "who" is closely related to location, which is evidently affected by the decision on "where". In short, necessity and completeness are two important criteria for decision of "who" and therefore it is important to target the right audience and make sure to include those who must be notified.

WHY

"Why" means the objectives and purposes of the notification that should be used to serve the ultimate goal of saving people's life and reducing possible damages. It is crucial that people who might be affected by disasters must be made aware of potential risks, and advised and assisted to take appropriate actions in order that they will know how to protect themselves from the danger they may face. In this regard, there are three types of notifications with different purposes – warning, instruction and reporting. Warning is to make people aware of potential dangers, without knowing which, people may be exposed at risk and may lose their properties or even their lives. Instruction is to provide guidance for people to take actions. It is crucial to provide instructions on how to cope with the disasters. Without being given instructions, people may respond to a threatening situation in an inappropriate way [43]. Reporting is to inform the event status and progress that can be used to inform the public, to reduce confusion and panic, and call for public support.

Accordingly, the critical decision problem here is: How to balance multi-objectives and to analyze people's possible behavior and reaction to notification? The decisions on "Why" depend on the stage of emergency response, the expectation of target receivers, and the impact of notification.

WHAT

"What" includes in notification's component and the content. A notification may consist of: the issue time, the source/senders, the receivers, the subject, and the main body. Issue time reflects the currency of notification. The source can help receivers judge the authenticity and reliability of notification. The receivers in notification can enable them to identify whatever is relevant to and useful for them. The subject provides the highlight and the purpose of notification and the body contains the main contents of notification. For warning

notification, it should indicate the nature, the probability of occurrence, and the possible impact of a disaster and so on. For instruction notification, it should tell people what to do under what conditions, and it may contain the measures, steps and explanation for actions to be taken in emergency [43]. For reporting notification, the notification should contain the current status and other information to exhibit empathy and comfort to receivers [44].

Then a critical decision problem in "What" dimension is: How to determine the right content of notification in order to meet its objectives? The content, which mainly depends on the purpose of the notification and expectation of receivers, should be important, brief, easy to understand, complete, credible, and consistent [44].

HOW

"How" refers to the manner of notification delivery. Different channels could be used for this purpose, including sirens, radio broadcast, television, telephones, leaflets, newspapers, Web postings, e-mail, and various wireless communication channels (e.g., pagers, cell-phones and SMS) [27, 41]. In an emergent situation, preliminary methods of communication like mouth shouting, door-to-door notification, and personal contact can help as well [43]. Sometimes, multiple channels of delivery are needed in emergency, not only because every technology has its vulnerabilities, but also because people almost always require confirmation of warnings from multiple sources before they act [45].

Within the "How" dimension, the critical decision problem we need to deal with is: How to reach the targets in most effective and reliable ways? The channel selection must meet the criteria of availability, feasibility, reliability, affordability, reach, responsiveness, and richness. Among these criteria, availability means if the channel exists and works at the time of emergency. Sometimes a communication channel may be damaged or not function due to one disaster. Reliability concerns the degree of channel's availability or endurance, and reach means who and how many can be reached by the notification channel. This includes the coverage of notification and the selectiveness of the receivers. Responsiveness points to the speed to reach the target receivers. Richness implies the ability of information to change understanding within a time interval through the notification channel(s) [46]. Sometimes it is related to the types of the media and the bandwidth of the channel.

4. The Decision Support System for Notification

We propose a system-architecture to support decision making of notification shown in Figure 1. The system consists of four components: the crisis event database, the crisis management knowledge base, the source database, and the geographic information system. For each decision-making dimension, the system supports a group of tasks are listed in Table 2.

The Crisis Events Database stores the information about the current and historical crisis including the events, the actions taken in emergency response, and the status of disaster. The Crisis Management Knowledge Base contains a decision model and policies related to emergency responses such as notification triggering rules, disaster spreading models, disaster human behavior model, notification template, channel selection model etc [47]. The Resource Database keeps environment and resource information that can be used for emergency responses such as the information about the communication infrastructure, the assets, the population, the authorities and response teams etc. Geographic Information System (GIS) displays and manipulates a variety of location related information on the map. It serves a graphic interface for notification decision making [17].

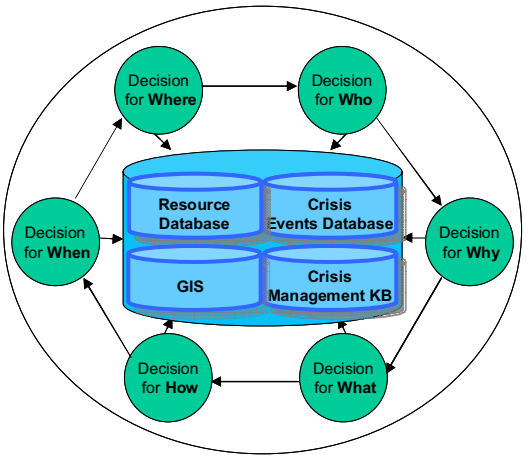

Figure 1. The architecture of decision analysis for notification

Table 2. Tasks and Support Technology for Notification

When	1) Identify events and threshold for notifications; 2) Set the right time and frequency to deliver the notifications	1) Triggering mechanism in the crisis knowledge management database.
Where	1) Identify original locations of disaster; 2) Find out spreading pattern of the disaster; 3) Identify possible locations impacted by disaster; 4) Locate available resources for rescue	1) Disaster spreading models in the crisis knowledge management database. 2) GIS
Who	1) Identify relevant parties for notification; 2) Set up the priority for each group of receivers	1) Information about the roles and responsibilities of various parties (authority and response team) in the resource database. 2) Population distribution, demographic data, resident contact in the resource database. 3) GIS
Why	1) Identify the needs for notification; 2) Determine the objectives and purposes of notification	1) Events and activity information in the crisis events database. 2) The previous knowledge in the crisis management knowledge base. 3) Human behavior model in the crisis management knowledge database.
What	1) Collect relevant information; 2) Tailor information to better fit the receivers and the purposes of notification; 3) Organize information in right form	1) Notification templates in the resource database. 2) Public reaction model toward notification in the crisis management knowledge database.
How	1) Identify available channels; 2) Find suitable channels to deliver notifications	1) Information on local communication infrastructure in the resource database. 2) The channel selection model in the crisis management knowledge database.

In order to complete the decision tasks, we can adopt some information technology for each dimension decision making as described in Table 2.

For "When" decision, it is important and yet difficult to determine the right time to send emergency notification under time pressure [4], which includes two steps, calling for and authorizing a quick and appropriate response [43]. Rules must be set to ensure that the authorizing will be triggered as soon as the impact level of disasters reaches a certain threshold [15]. As well, the frequency of notification needs to be set according to the memorability and importance [44]. This triggering mechanism can be programmed in advance and stored in the crisis knowledge management database [43]. For authorizing steps, the approval mechanism is used to verify, authorize and execute the notification delivery [26]. For example, the warning message triggered by monitoring results will be reported to the responsible crisis management center, sometimes by the hotline, to authorize whether the notification be send out or not.

For "Where" decision, determining a disaster's location takes top priority. This should be followed by assessing the spreading patterns of the disasters for different disasters may have different spreading patterns which could affect the scopes of the disasters. For example, the area impacted by fire is determined by such factors as nearby circumstances and the weather. The epidemic may spread through populations infected (e.g., SARS, bacterium, or other diseases). Disaster spreading models can be used to predict the scope, the impact, and the trend. The results can also be displayed on a map using GIS. The distribution of the resources on hand and on order for rescue can be accessed from the resource database and displayed on the map as well.

For "Who" decision, we need to determine the notification targets promptly based on the geographic location of the impact area with the help of GIS. The targets may include authority, response members, and possible victims. To this end, information about the roles and responsibilities of various parties (authority and response team) can be accessed from the resource database [3]. The population distribution, demographic data, resident contact information can be retrieved from the resource database too. The possible victims with different risk levels exposed to them can be identified according to the location and impact level of disaster with the help of resource database and GIS [17, 43].

For "Why" decision, the purpose of a notification should be determined based on the stage and the trend of emergency, as well as the needs and expectations of the receivers. The stage can be determined based on event and activity information stored, updated, and retrieved from the crisis events database. The trend of emergency may be predicted based on the previous knowledge in the crisis management knowledge base. For instance, an earthquake will initially cause many deaths and injuries, which, without sufficient resource for basic life and sanitary support, may result in epidemics as a main threat. The purpose of notification should also be adapted accordingly. In order to understand the current and future needs of receivers, a human behavior model in emergency might be helpful, which can be stored and accessed from the crisis management knowledge database. For example, when people feel frightened, anxious, and confused in a crisis, we can make these feelings go away through a warning and reporting with empathy.

For "What" decision, notification templates can be used to provide a structured medium to organize relevant information in an easy and timely manner and there is no need to change the format of template. We can develop the corresponding notification messages only by editing and tailoring the contents of the corresponding template. At the same time, we need to develop the model of the public reaction toward notification to assess the aftermath of notifications in order to avoid the public panic caused by the improper notifications.

For "How" decision, different channels have different attributes and applicable conditions. In order to select the proper channel to deliver the notification, we need to access information on local communication infrastructure from the resource database. An important consideration is the channel availability some of which may be damaged, and alternative or preliminary method need to be considered. A multiple criteria decision model for channel selection that can be stored and accessed from the crisis management knowledge database may help to make notification effective.

5. Conclusion

In this paper, we have proposed a 6WDs, which includes "when, where, who, why, what, and how" as our decision analysis framework in the hope of enhancing the effectiveness and efficiency of emergency responses. In correspondence, some critical issues and criteria of each dimension are identified and elaborated. A system architecture for decision analysis support is also proposed and discussed.

In summary, notification is one of critical tasks for responding to emergency and crises and it should be delivered to the right people at the right moment with right contents and objective by right channels. Furthermore, a decision support plays a vital role for emergency domains because it provides well-founded principles for making critical decisions. As well, a decision support needs previous learned experience while low probability means the data are hardly available or even non-existent. Decision-theoretic methods require the development of complete models, a time-consuming task ill-afforded in crisis domains with their characteristic of urgency. The limited amount of time for decision-making also constrains the development of alternative courses of action and their subsequent consideration.

In short, a disaster is likely to be characterized by high consequences, low probability, sometimes unprecedented, a short decision time and big uncertainty, which creates a unique and threatening decision-making environment where decision-theoretic techniques are particularly difficult to implement because of the characteristic high consequence that means a need for making decisions about life and death. This is the challenge we face for decision support in emergency, for which, we will continue to do well whatever is needed with the support of technology, but not driven by it.

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