Information Requirements for Disaster Victim Identification and Emergency Medical Services: Hajj Crowd Disaster Case Study

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ABSTRACT

Disturbing crowd disaster incidents have been witnessed in every corner of the planet, which often lead to extensive difficulties, especially when they involve mass multi-nation casualties. When conducting Disaster Victim Identification (DVI) tasks, starting from finding the missing, curing the injured, and identifying the deceased, the challenge in such disasters is the lack of information to provide Emergency Medical Services (EMS) and conduct DVI in a timely manner. The literature presents fragmented solutions that can equip either post-mortem DVI or EMS with solutions to facilitate data collection and dissemination, but they do not consider a holistic solution that allows access to the victims' right information when needed. In this paper, we analyze information needs across multi-disciplines, as well as the requirements for technical support that can help manage the identification process. Recommendations should lay a sound foundation for future multi-disciplinary research in the areas of DVI, EMS, crowd disaster, health informatics, information security and software engineering in the health sphere.

KEYWORDS

Crowd disaster, Disaster victim identification, Emergency medical services, Hajj stampede, Information security.

INTRODUCTION

As the world's largest gathering (Ministry of Health (MoH), 2017), approximately 4 million pilgrims from more than 50 countries around the world travel to the holy city of Mecca to complete the Hajj rituals (i.e. Islamic Pilgrimage to Mecca). In these overcrowded conditions, human stampedes can occur, resulting in many injured people. Over the years, crowd incidents have happened on both a small and large scale during Hajj (Manoochehry and Rasouli, 2017). Moreover, being in a crowd is a situation that often cannot be avoided in our daily life. Some types of crowds are ad-hoc, such as riots or crowd attacks, but another type of crowd is voluntary, such as when someone is attending a football match or political event, during transportation or a funeral procession of famous people, or concerts in a large hall. Identifying the injured, dead or missing people in a crowd disaster is an elusive, complicated and time-consuming task. Many crowd studies have recognized that the forces of a massive gathering are almost impossible to control; fatal incidents occasionally occur, and the emergency response has been challenging (Ngai, et al., 2009; Santos-Reyes and Olmos-Peña, 2017).

The major challenge facing DVI and EMS teams in multi-national situations is the collection of the right information about the victims to find those missing, cure those found, and identify the deceased. Due to victims' demographics and the involvement of multiple stakeholders, governments are left with no option but to request help from external intergovernmental organizations, such as Interpol, to manage multi-DVI and EMS teams for each nation with victims involved. First and foremost, Interpol, as well as local police investigators, follow a traditional approach towards identifying missing persons in such open disasters, where families and friends report missing people by completing lengthy forms with fine-grained details about any identifiable information they can possibly record to help find them; examples in (Interpol, 2013a, 2017a). Some researchers have proposed a solution to address missing persons list identification and generation. Manoochehry and Rasouli (2017) suggested an early warning deployment of computerized software systems and camera monitoring, which can identify lost pilgrims, update their locations, and alert their group guide. However, those solutions are limited to the number they can manage at once. In addition, they are more victim rather than disaster-oriented, which renders them effective to search for a particular victim and it does not automatically generate a missing persons list for a particular disaster. Second, EMS provision for injured victims' needs to be done in a timely manner as time is critical. Therefore, paramedic teams need to access victim-related medical information immediately to provide healthcare services to victims; without these details, informed decisions (as simple as blood transfusion) cannot be made to decide the best way to save the victim's life. Therefore, several articles have suggested the enhancement of health and management approaches, such as an intervention (Salamati and Rahimi-Movaghar, 2016), health responses (Shujaa and Alhamid, 2015), and management of injured victims (Ganjeh and Einollahi, 2016). Third, DVI is "*the formal process whereby multiple individuals who have died as a result of a single incident have their identity established through the application of scientifically proven techniques*" (Victoria Institute of Forensic Medicine, 2014). Therefore, DVI plays a significant role in identifying deceased victims, where experts with different backgrounds and specialties need to collaborate in the case of a disaster.

When a major disaster occurs with mass fatalities, such as the Hajj stampede, the process of identifying victims is rarely possible by visual recognition (Interpol, 2017a), and thus often requires obtaining a conclusive identification through fingerprints, dental records, facial recognition, or DNA samples comparison with ones already stored in databases or taken from victims' personal belonging reference (Interpol, 2017a) and biological samples from the victims' families (Ritter, 2007). However, research is limited regarding DVI needs, and how to find information promptly on victims of Hajj crowd incidents. Currently ante and post-mortem information is, to a certain degree, still performed manually, and solutions in the literature mostly focus on helping post-mortem DVI teams in recording data collected from deceased victims' remains, such as in (Colville-Ebeling et al., 2014), but no research so far has focused on how to collect ante-mortem data and automate the comparison for the identification. Furthermore, some solutions are limited to a specific number of victims and are neither fast nor accurate, which renders them ill-equipped for investigations of mass fatalities incidents (Levinson and Domb, 2016). Finally, the lack of comprehensive solutions that would allow the availability of the right information for the DVI and EMS hampers them from achieving their tasks. Technology is one of the solutions that can mitigate the risk of deadly crowd incidents during Hajj, but the existing technology solutions are fragmented to focus on one team's needs, and lack a holistic solution that would equip DVI and EMS with the technology needed to achieve their goals in a timely manner.

In this paper, we use Hajj as a case study to investigate the information, as well as the technical needs for DVI and EMS teams to find the missing disaster-victims, cure the injured, and identify the deceased. The contribution of this paper is threefold. First, it identifies victims associated with a disaster, and classifies them into victims identification status lists. Second, it defines the set of information criteria required by the DVI and EMS teams for each victim status; Third, it identifies a set of required features of alternative technology to accelerate the DVI and EMS tasks and minimizes casualties and loss and it assesses security and privacy risks that may arise due to the collection, processing and usage of the victim's data. The remainder of this paper is organized as follows. The Hajj Ritual section explains the basic information of Hajj rituals and common crowd disaster risks. The following section summarizes the literature review and methodology. The DVI current practices section presents the analysis of the information needs. The methodology section defines the research approach, following which, the results section presents the results from the analysis and lists the set of recommendations for future research. The following section, technical challenges, discusses in detail the opportunities proposed by seamless sharing, suggests information security risks, and raises privacy concerns at the same time. Finally, a conclusion is drawn in the last section along with suggestions for future research.

BACKGROUND AND LITERATURE REVIEW

Hajj Ritual Pathway

Hajj ritual involves ten tasks to be completed by all pilgrims in about four consecutive days in five different geographical locations (most of them are limited in terms of their space) representing a pathway: *Migat*, The Holy Mosque (also known as *Al-Masjid Al-Haram*), *Mina*, *Arafat*, and *Muzdalifah*. In order to illustrate the Hajj ritual process followed by pilgrims, we modeled their journey using Business Process Modeling Notation (BPMN). Figure 1 shows the Hajj ritual journey including: different sites, processes, order, and time restrictions for each move. Tasks are described in detail based on each day as follows:

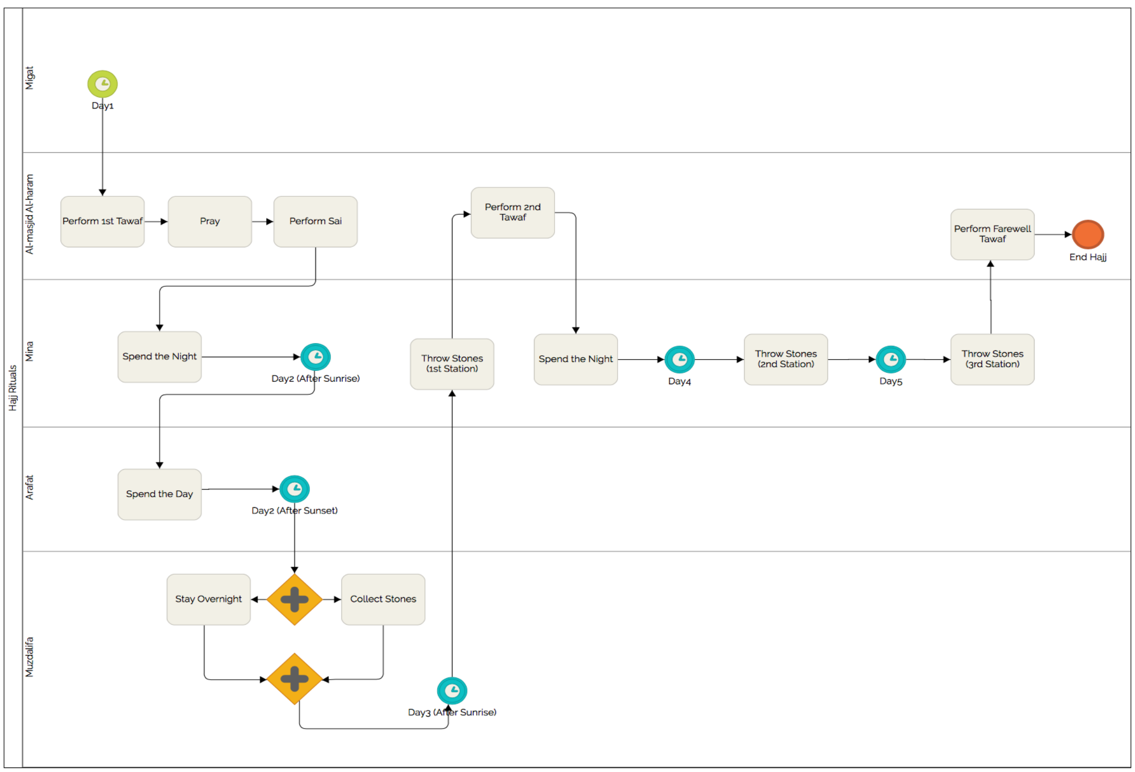

Figure 1 Hajj Ritual Journey

Day One

Hajj is initiated by reaching the *Miqat* before entering the holy city, Mecca. It is one of the points where the state of Hajj starts. Once pilgrims are ready, they head next to *Al-Masjid Al-Haram* to perform three tasks: Tawaf, (i.e. going around *Kabah* seven times in a defined manner), a prayer, and Sai (i.e. walking quickly between two small hills, *Safa* and *Marwah*). Thereafter, the pilgrims travel to *Mina* where they spend the night on this first day.

Day Two

Pilgrims travel 20 km by public transportation from *Mina* to the mountain of *Arafat* where they keep praying until sundown. After sunset, they leave for *Muzdalifah* and stay overnight to collect stones for their next tasks.

Days Three and Four

Pilgrims return to *Mina* to perform the symbolic throwing of stones at the first pillar representing the temptations of the Devil. Afterwards, the pilgrims return to Mecca to conduct the second *Tawaf*, return to *Mina* to spend the third and fourth days stoning the second and third pillar consequently, repeating the symbolic throwing of stones, and then return to Mecca for bidding farewell to *Tawaf*, before finally leaving Mecca.

During the Hajj, pilgrims are exposed to many risks and incidents, as a large number of pilgrims need to strictly follow the Hajj ritual journey at the same time. Risks and incidents include: fire incidents, crushes, injuries and stampedes, as well as infectious disease outbreaks (MoH, 2017). Two of the most prominent Hajj crowd incidents occurred in July 1990 and September 2015 (Ganjeh and Einollahi, 2016). In 2015, the whole world witnessed the deadly stampede incident which occurred in Mina when the pilgrims were conducting the stoning of the pillars; this killed a total number of 1,849 pilgrims (The_Guardian, 2015a), and that was not the first time Hajj had been marred by crowd-related accidents and tragedies (The_Guardian, 2006; 2015b). In 1990, a stampede happened inside a pedestrian tunnel leading out from Mecca towards Mina.

Religious Events and Crowd Incidents

Disasters during mass gatherings have repeatedly occurred throughout history. Soemaroo and Murray (2012) examine mass gathering disasters that occurred between 1971-2011. There were some major disaster crowds with mass casualties, such as a crush between fans entering and exiting an event venue; crowd surge and crushing; fireworks causing a fire; stairways fires in front of emergency exits; overcrowding of fans leading to a stampede. Crowd disasters frequently occurred in large events such as football matches, Olympic games, music festivals, firework events, and religious events, such as Hajj. The reasons for the mass casualties were various, but Soemaroo and Murray (2012) conclude that there are five categories of the causes of crowd disasters: overcrowding and crowd control, event access point, inadequate fire safety measures, medical unpreparedness and slow emergency response. Overcrowding could happen because of tickets being oversold for big events, such as football matches and music festivals, poor estimation of crowd numbers, and efforts to control crowds using tear gas leading to panic and human stampedes. Sometimes, crowd disasters are caused by a lack of safety measures, such as fire protocols or delays in emergency response (Soemaroo and Murray, 2012). At times, EMS could not access the disaster site causing response delay, such as in the Ramstein airshow disaster (Martin TE., 1990), or there were no routes available for the responders to reach the stampede location.

Religious events and crowd incidents such as Hajj crowd disasters have been the subject of scientific investigation related to crisis management (Helbing et al., 2007), which is considered equally as important as other crowd research on religious gatherings, such as the stampede case in the Kumbh Mela (Greenough, 2013), or examples of various human stampede cases during religious festivals in India (Illiyas et al., 2013). The Hajj disaster in 1990, causing the death of 1,426 pilgrims, occurred when they spontaneously rushed to leave Mecca via one exit. Such major crowd disasters have occurred many times and there are similarities in these major events, i.e. missing people or fatalities.

Numerous studies suggest the use of technical solutions to improve the management of Hajj or to better prepare in case of disaster, such as: crowd-sourced data collection and context aware services, big data cloud computing, intelligent shelter allotment for evacuation planning, pilgrimage tracking using both RFID and mobile systems/wireless devices, and multimedia surveillance event detection. Ahmad et al. (2014), for instance, suggest a spatio-temporal ritual service *HajjNUmrah* framework that exploits smartphone sensors to locate pilgrims, sense the environment, geo-tag people with severe health issues and social networks tailored to the Hajj ritual. In a normal situation, such applications may enable people stay connected and allow them to call in case of emergency, but they are not at all effective in identifying the injured or deceased in a crowd disaster. *SmartCrowd* (Ali et al., 2015) is a mobile cloud computing system that offers information and communication services during the Hajj. The data from pilgrims' smartphones can be used for locating high-density concentration points to be analyzed and mapped. However, there is no further information on the implementation part of *SmartCrowd*. Similarly, multimedia surveillance event detection is suggested as an alternative technology by Al-Salhie et al. (2014). A smartphone-based *Hajjlocator* (Mantoro et al., 2011) is proposed to solve the issue of missing pilgrims. The prototype of the mobile application is designed in such way that one can track and monitor individuals in a crowd. Both *SmartCrowd* and multimedia surveillance are useful features that allow EMS to remain alerted regarding potential crowd disasters from different areas with high-density locations. Likewise, tracking people is possible through *Hlocator* and this is mostly useful for groups conducting Hajj together. Other solutions focus on wireless communication sensor networks to provide assistance to pilgrimages (Alwakeel et al., 2014). A crowd controller has been proposed (Yamin and Albugami, 2014) for monitoring transportation, health care services, ritual services, security services and improvement of Hajj management. Meanwhile, intelligent shelter allotment for emergency evacuation has been proposed (Yang et al., 2015) for pre-planning under various evacuation scenarios, which will contribute significantly towards improved emergency management. However, in the literature, how to improve victim identification when disasters actually occur remains unsolved.

DVI, Forensic Practices and Technologies

Although there is extensive literature focusing on how to improve crowd Hajj management, there is very limited research dedicated to DVI on large-scale crowd tragedies such as in Hajj or other religious gatherings, even though both issues are equally important. DVI is part of humanitarian and legal responsibility where investigators should identify every individual, when possible, so that the victims can be returned to their family to help with their grief (Interpol, 2017b). Victim identification is, indeed, part of forensic medicine and crime investigation. However, there were variations from time to time regarding how victim identification should be conducted, as explained by De Alwis (2011). There was a period where the post-mortem identification was not performed in the field, and should only be performed by a medical officer. Later, on-scene investigation was introduced where the expert (a medical officer) would observe the scene, take notes and photographs, and carry out basic medico-legal investigations, but not carry out the post-mortem examination. Afterwards, the first personnel to arrive at the scene where a dead body is lying are specially trained police officers to preserve the scene and conduct relevant investigations until the arrival of senior police investigators, the magistrate, medical officer and forensic scientist. Most of these techniques are valid for individual forensic investigations. The DVI for mass causalities was introduced later, which means that in previous mass tragedies involving numerous victims, such as tsunami disasters, airplane crashes, and crowd tragedies, the majority of victims were not identified.

Modern technology introduced new techniques, such as photographic evidence, X-ray for mortuary, DNA technology and other means for identification, such as fingerprint, eye print, handprint, leg-print. Post Mortem Computed Tomography (PMCT) scanner (Morgan et al., 2014), radiography and fluoroscopy (Viner et al., 2015) are used for mass casualties. Dental radiographs/forensic odontology is a robust alternative for human forensic identification (Rindhe and Shaikh, 2013), used when other information is not available. In forensic odontology, the victim identification is performed based on dental features, as teeth are parts of the human body that are not easily damaged, and this is considered as a reliable tool for DVI. There are numerous suggestions introduced to improve forensic odontology. Debbarma and Nath (2014), for instance, suggest a contour and skeleton-based shape extraction used in matching algorithms for dental radiographs. The DVI has recently gained more attention as part of forensic techniques. However, in the existing literature, how resource and time intensive DVI can be applied during mass fatalities such as the Hajj crowd disaster remains unresolved. In the following sections, we briefly introduce the development of DVI and existing standards and regulations.

DVI Current Practice

The Hajj stampede, similar to many other large-scale crowd disasters, is a subject of international investigation as the victims are often citizens from multiple countries. The International Criminal Police Organization (ICPO) or Interpol, is an intergovernmental organization facilitating international police cooperation, making it the world's largest international police organization, bringing 192 members to represent their countries under its umbrella (Interpol, 2017c). When a major disaster occurs, one country alone may not have sufficient resources to deal with mass casualties. In some cases, the incident may have damaged or destroyed the country's existing emergency-response infrastructure, making the task of victim identification even more difficult. Therefore, Interpol established the first working party on DVI in 1982 to tackle this challenging issue (Interpol, 2017a). The first Interpol DVI Guide was issued in 1984 and was subsequently revised over several years, and the most recent one was published in 2014 (Interpol, 2017a).

DVI is the formal process whereby multiple individuals who have died as a result of a single incident have their identity established through the application of scientifically proven techniques (Hallam et al., 2005). Therefore, DVI plays a crucial role in law enforcement criminal investigations and interrogations. When a major disaster occurs with mass fatalities, the process of identifying victims is rarely possible by visual recognition (Hallam et al., 2005), and thus DVI often requires obtaining a conclusive identification. Furthermore, DVI teams work collaboratively, in an interdisciplinary manner, engaging the services of experts in various disciplines towards the identification of victims. DVI teams are encouraged to cooperate with other national DVI teams. Currently, the basis for coordination and response that require DVI includes: first, Legislation, Jurisdiction and National Conventions; second, Interpol DVI Standards; and finally, Command and Control arrangements. The DVI process consists of four phases (see Figure 2):

Phase 1- Scene

The team investigates the human remains and property at the disaster site.

Phase 2- Post-Mortem (Victim Data)

The team conducts a detailed examination of human remains in the mortuary. It collects detailed data, such as fingerprints and skeleton sketches, in addition to the data that are collected during Phase 3 (See Ante-Mortem data).

Phase 3- Ante-Mortem (Missing Person Data)

The team collects missing person data from various sources. This task is initiated with collecting and recording all information related to individuals who may be regarded as potential disaster victims (Interpol, 2013). This process starts only when a victim has been identified as missing. The data can be collected from the missing person's family, relatives, and/or friends.

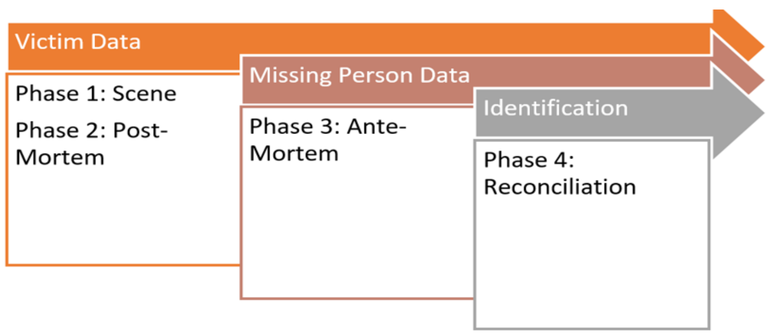

Figure 2. The DVI Process (Interpol, 2017a)

Phase 4- Recognition

The DVI teams match/cross reference post-mortem and ante-mortem data. The combination of Victim Data and Missing Person Data will lead to Identification, and conducting recognition. Victim Identification is done by preparing a list of special Ante-Mortem and Post-Mortem key markers for bodies using only particularly noteworthy features of a missing person or body recorded in a list.

DVI teams consist of the following experts:

- Photographers, Radiologists and Interview Teams
- Property Managers
- Scene and Post-Mortem Recorders and Quality Assurance Teams
- Evidence Collection and Management Teams,
- Mortuary Managers
- Investigators, Logistics, Liaison and Missing Persons Officers
- Information Technology Specialists

According to Interpol (2014), disasters can naturally be classified as open or closed, looking at it from the DVI's perspective. On the one hand, an open disaster is a catastrophic event resulting in the death of unknown individuals for whom no prior records or descriptive data are available. The Hajj stampede is an example of an open disaster. A closed disaster, on the other hand, is an event where there has been the death of a number of individuals belonging to a fixed, identifiable group (e.g. aircraft crash with a registered passenger list). DVI in an open disaster is more challenging and requires both technology and experts' support.

In Europe, the FP7 EU funded project FASTID has introduced an international Missing Persons and Unidentified Dead Bodies (MPUB) database in Interpol secretariat (Interpol, 2013b). FASTID was created due to the unavailability of a centralized database at both regional and international level. Even if the data existed in some regions, the database was not interlinked. MPUB database allows for searching of items such as DNA and dental records. It also integrates its interface with other databases, such as fingerprints (Interpol, 2013b), which greatly supports the DVI tasks. However, in crowd incidents such as the Hajj, the situation is more complicated as there are many nationalities involved, and thus the biometric data is not always available in such databases for all countries. Also, the victims could be from countries that have no link to MPUB.

Current Forensic Practice in Saudi Arabia

Concerning the legislation related to forensic identification process in Saudi Arabia, Alqahtani et al. (2017) identify that there are two relevant government agencies involved in such cases, i.e. The MoH and The Ministry of Interior (MoI). The MoH, on the one hand, is the main regulator of forensic issues and the party responsible for the technical supervision of forensic activities in the country. The Ministry issues a set of instructions and procedures to guide the doctors performing forensic duties. On the other hand, the MoI conducts the investigations, arrests the perpetrators, and establishes the claims before the courts. However, they work exclusively, where each department establishes its own protocol in dealing with the forensic investigation. Alqahtani et al. (2017) list several issues regarding current forensic practice in Saudi Arabia:

- No clear national guidelines or protocols for personnel dealing with forensic cases (photographs, radiographs, descriptive report or methods to be used).
- No protocols in the hospitals on reporting or documenting cases that arrive during the emergency.
- No standardized report forms to describe the detailed cases to the court and typically they are sent directly to the judge without the need for the expert witness to attend.
- No references and limited accuracy.
- No minimum and maximum range of age estimation reports or the method used to reach that estimation.

In addition, when applying forensic odontology techniques, official forensic forms that document oral findings are available in Arabic only, and do not include the complete dental status. Tooth abbreviations, color distinction, supplementary examination, types of radiographs taken and methods used in the analysis are not documented. In brief, there are huge challenges in handling mass fatalities as DVI is not fully supported by current legal practice, and can lead to inefficiency in the DVI workflows.

Finally, this section clearly identifies the number of fragmented solutions that can equip post-mortem DVI to help with the data collection and dissemination. It also identifies the gap in the literature that needs to be bridged with a holistic solution that allows for victims' appropriate information to be accessed by the right team member at the right time.

METHODOLOGY

Initially, the information requirements identification for DVI and EMS followed the requirement elicitation and analysis cycle in Figure 3 (Sommerville, 2016). This requirement elicitation and analysis cycle involved stakeholders with different areas of expertise to discover, classify, organize, prioritize, negotiate and specify these requirements.

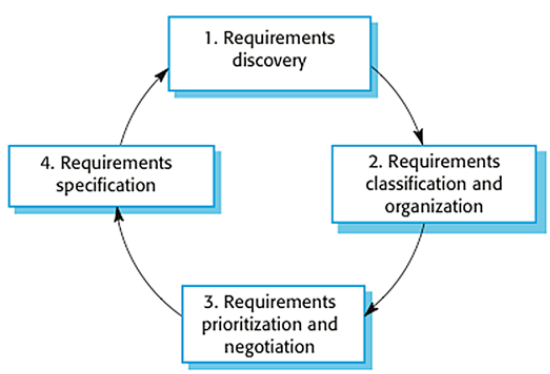

Figure 3. Requirement Elicitation and Analysis Cycle (Sommerville, 2016).

The methodology involved the following key phases:

- Define the complete Hajj process in terms of activities, locations, users, and information requirements.
- Design and model the scenario of the Hajj ritual using BPMN to illustrate the process and the challenges it includes (see Figure 1).
- Classify victims in a disaster into four scenarios based on the identification stage lists: Alive and Well, Alive and Injured, Indirect Confirmation through an emergency contact, and Missing person.
- Discuss and revise challenges for each class of victims as seen by DVI and EMS teams in worse case scenarios.
- Identify the gap.
- Validate the requirements.

Within discussion groups, the initial requirements were refined to generate the requirement specifications. A total of at least sixty-seven hours of brainstorming sessions were conducted jointly and individually with experts in thirty-three fields over the course of sixteen months distributed as listed in Table 1 and 2:

Table 1 Fields of Expertise

Total Fields of Expertise	**Team Member Expertise**	**Total number**
33	Physicians	2
	Health informatics experts	2
	Information security experts	4
	Computer scientists	8
	Saudi Red Crescent authority representatives	7
	DVI Dentals team members from Saudi Arabia, Italy, Australia, and Brazil.	4
	Disaster Mortuary Operational Response Team (DMORT) members from USA	2
	Members of Interpol and one forensic deontologist.	4

Table 2 Contact Hours with Discussion Groups

Discussion Groups		
Total hours	Specific hours	Specific Team
67 h	34 h	EMS
	33 h	DVI

These results include a set of information requirements for DVI and EMS to allow them to find the missing, rescue the injured, and identify the deceased.

RESULTS

This section summarizes the results from the analysis and synthesis we performed on the primary and secondary data collected from the experts in eight different fields. The results present the classification of victims, as well as the classification of information required by the DVI and EMS teams in Hajj crowd incidents and discusses the technical challenges.

Victims Identification Lists

According to the Interpol guide (Interpol, 2017a), missing persons' lists cannot be confirmed until forty-eight hours from when the disaster happens. Therefore, and in order to generate a final missing persons list for DVI teams, a list of victims in an identified disaster must be added to one and only one of the following four lists shown in Table 3 below.

Table 3 Victims' Lists and Descriptions

No.	List Name	List Description
1	**Alive and Well List**	Victims who are found alive within the first 24 hours and do not need any medical attention.
2	**Alive and Injured List**	Victims who placed an S.O.S. call within the first 24 hours and need medical treatment.
3	**Pending Confirmation List**	Victims who did not place an S.O.S call within 24 hours, and before the following 48 hours pass, an emergency contact is contacted to request the whereabouts of the identified victim and his/her health status. If the emergency contact has already responded and supplied updated information about the targeted victim, this is listed in this list.
4	**Missing Persons List**	Victims who were neither reached within the first 48 hours nor their emergency contact reached, are considered missing.

Information Requirements for DVI and EMS Teams

For each victim in any of the three lists, specific information needs to be accessed by either the DVI team or EMS team. This information is classified based on the task needed for the victim's case, whether because he/she is missing, injured, or deceased. This is shown below in Table 4.

Table 4 Summary of Information Requirements for DVI and EMS Teams and Access Control Rights

Information Required	Victim's case task			Task Purpose	Access Control Rights
	Cure the found	Find the missing	Identify the deceased		
Medical records	✓			Medical treatment, first aid	EMS teams
Blood type	✓			Medical treatment, first aid	
Family members	✓	✓	✓	Help find victim and/or return them to the family	
Affected person lists	✓	✓	✓	Medical treatment, first aid	
Alive/injured list	✓			Help responding to victims within 24h	
Pending confirmation lists		✓	✓	Contact next kin if no response after 24h-48h	DVI teams: law enforcement officials, deontologists, DNA and fingerprint specialists
Missing person list	✓	✓	✓	If no response from victim and next of kin after 24-48h, missing person will be listed as missing	
Victim's registered information (dental x-ray, dental work, fingerprints)			✓	Post/Ante-Mortem	
Basic information of the victims			✓	Ante-Mortem	
Body description (weight, height, eye colors)			✓	Post/Ante-Mortem	
Pathology			✓	Post-Mortem	
DNA (blood from the core of the body, deep muscle tissues, bones or teeth)			✓	Post-Mortem	
Skeleton sketch			✓	Post-Mortem	
Original medical/dental record, medical practitioners and dentists consulted by missing person			✓	Ante-Mortem	
Blood samples from parents/children of missing persons			✓	Ante-Mortem	

Technical challenges: Security and Privacy Risks

Table 4 shows the information criteria required and the access rights for the EMS and DVI teams which could be used as guidelines for the list of features required, including functional and non-functional requirements for software and technical solutions of mobile applications on mobile or wearable devices to connect victims with DVI, EMS, and rescue teams in real time to allow them to find the missing, cure the injured, and identify the deceased. For the different actors, the tasks and information needs are as follows:

- Victims; place an S.O.S emergency call in the event of an incident.
- Rescue teams; access a list of injured victims and share their geo-location and medical information with the local rescue team to prepare for EMS who provides medical treatment.
- DVI teams; access a list of victims "last seen" within a close range of the identified disaster and share it along with their geo-location with the local DVI teams to try to find them and have access to their essential identifiable information to speed up the identification of victims.
- EMS teams; access list of injured victims and their medical information.

Access Vs. Privacy

Although the above solution encourages openness and seamless sharing to paint a full picture that would allow each team to perform their tasks, it nevertheless raises information security and privacy concerns that could hinder its adoption. As mentioned above, different teams require specific victim-related information at various victim identification stages. Even though the need for personal identifiable information may improve the quality of DVI work, the digitization of such information poses new privacy and security threats. Such threats include, among others, first, improper disclosure of sensitive information by privileged DVI professionals. Second, there is the threat of unauthorized access to personal information by persons taking advantage of the DVI environment, and finally, cyber criminals could gain access to valuable data such as health information.

Information security and privacy are major concerns for individuals and DVI team members worldwide. For instance, if we consider the medical information of victims (shown in Table 2), Vodicka *et al.* (2013) carried out a survey on online access to patient records and found that approximately one-third of participants were concerned about the security and privacy of their health records, particularly regarding who should have access to which item of health information. Furthermore, according to a survey by *IBM* and the *Ponemon Institute* in 2017 (US Department of Health and Human Services, 2017), many breaches involve personal information, such as protected health information theft, loss or improper disposal of medical records, and unauthorized access to, or disclosure of, health information. The above-mentioned findings demonstrate that it is essential to address security and privacy concerns regarding personal information. Furthermore, there is global governing legislation with which such a solution must comply. Such legislation has defined access restrictions to protect patient privacy and means of processing health records securely. Moreover, the "Health Insurance Portability and Accountability Act" (HIPAA) is an American legislation to ensure that health information is protected adequately while allowing the necessary flow of health information for providing and promoting high-quality healthcare (Nosowsky and Giordano, 2006, U.S. Department of Health and Human Services, 1996). Furthermore, Europe has similar legislation, including the EU directive (EU Directive 95/46/EC) (Directive, 1995) on the protection of individuals with regard to the processing of personal data and the free movement of such data. The General Data Protection Regulation (GDPR) (European Commission, 2016), adopted in April 2016, will supersede the EU Directive 95/46/EC and will be enforceable from 25 May 2018. Such standards and legislation also provide security and privacy suggestions to address the need to protect personal information.

However, to establish more secure and readily available services to DVI and EMS teams, there are many security and privacy challenges to overcome in the technical solution. Among those challenges are:

- User privacy and data protection
- Authentication and identity management
- Trust management and policy integration
- Authorization and access control

A number of concerns would be raised by the proposed solution, and so it is important to ensure secure use and sharing of victims' personal identifiable information. This is particular to such solutions when diverse stakeholders need access to fragmented, confidential information in a timely manner to gain a holistic view of cases under investigation. A major concern would be how to prevent privileged DVI teams from disclosing sensitive information improperly. A second concern regards to malicious users taking advantage of the DVI environment by having unauthorized access to personal information such as health information, among others. Improper disclosure or unauthorized access may occur when someone within the DVI team accesses shared information for unethical reasons, for instance, accessing a victim's health information for personal gain. In overcoming authorization and improper access matters associated with DVI, access control models, such as role-based access control (RBAC) (Ferraiolo, et al., 2001), attribute-based access control (ABAC) (Hu, et al., 2015) and others, may prove to be the answer. Access control is critical to the successful adoption of this solution to manage problems related to unauthorized and improper access.

CONCLUSION AND FUTURE WORK

Disaster incidents have been witnessed in every corner of the planet, and the world has mourned for victims affected by crowd and natural disasters, as well as acts of war and violence. Crowd disasters with mass multi-nation casualties often lead to vast difficulties and challenges, especially when conducting DVI tasks starting from finding the missing, curing the injured, and identifying the deceased. Frequently, such mass gatherings involve multiple citizenships, such as in the largest annual gathering, the Hajj, which is much more complicated to manage in the case of a disaster. Unlike closed gatherings, such as an airplane crash accident, for instance, when passengers are mostly well registered and accounted for, the main challenge in crowd disasters is the lack of medical information for rescue teams to provide EMS in a timely manner, as well as, identifiable information for ante- and post-mortem DVI teams of police investigators, DNA and fingerprint specialists, and odontologists to perform their tasks to bring justice to victims and closure to their families. This makes it an elusive, complicated, and time-consuming task that leads to the increasing number of causalities in such urgent situations, when time is critical to disaster victims. Practitioners have acknowledged the need for technical support for victim identification in such multi-nation mass casualties, especially in Hajj.

The literature offers a number of fragmented solutions that can equip either post-mortem DVI or rescue teams with solutions to assist with data collection and dissemination, but they do not consider a holistic solution that allows for victims' relevant information to be accessed by the right team member at the right time. In this paper, we used requirement engineering and business process modeling notations to analyze information needs across multi-disciplines, as well as the requirements for technical support that can help manage the identification process and analyze certain practical challenges that face such solutions with the benefit of insight gained from the Hajj case study. The requirements were refined with experts in nine specialties to identify: the information criteria required by DVI and EMS teams from each victim stage, the set of required features of a supportive technology to speed-up tasks and minimize causalities and loss, and the security and privacy risks. Results show that victims in the Hajj crowd disaster could be classified into either missing, injured, or deceased. Furthermore, each of those classifications represents a case which requires specific information that must be granted to a specific team in order to achieve the goal of that particular case. However, access control is critical to the successful adoption of this solution as a holistic view is required on each victim under investigation. A set of features is required by the DVI, EMS and rescue team to operate. For each DVI and EMS team member, information disclosure should be carefully studied to ensure they only retrieve the required information at the time they need it. Finally, the set of recommendations outlined in the results should lay a sound foundation for future multi-disciplinary research in the areas of disaster victim identification, medical emergency services, crowd disaster, health informatics, and information technology in the health sphere. Suggested future work includes the use of the requirements identified in this research to develop an alternative technology that can support faster response? in mass casualties such as the Hajj crowd incidents. With such a tool, the security and privacy risks could be identified, as a technical concern should also be considered to facilitate the implementation of a solution and overcome the current technical challenges. The solution should mainly focus on the technology that can help the EMS and DVI teams to respond faster in terms of finding the missing, curing the injured, and identifying the deceased.

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