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Original Article

Designing an Architectural Model of Crisis Management Information System for Natural Disasters in Iran

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Abstract

Introduction: The crisis management information system (CMIS) is a mission-critical system that enables the crisis management team for understanding, diagnosing, interpreting, analyzing, structuring, and making decisions faster by providing timely and high-quality information at the right time. The purpose of this research is to provide an architectural model of a CMIS for managing natural disasters in the process of finding trapped victims and relieving them.

Materials and Methods: This applied study was conducted in 2020 in two stages. First, data on CMIS used in selected countries were collected from electronic resources and digital libraries and were then analyzed. Next, a preliminary model of CMIS architecture including three aspects of informational content, applications, and technological requirements, was prepared using these systems and experts' interviews. Finally, the architectural model of CMIS validated by the Delphi technique and the focus group.

Results: The analysis of experts in three rounds of Delphi test for three aspects of informational content, applications and technological requirements in the architectural model was performed with the presence of experts at the national level and the consensus rate over 75% was obtained for 7 modules and 28 proposed components of the CMIS.

Conclusion: The architecture of information systems has a direct impact on the performance of these systems. Using an appropriate architecture for CMIS can be an effective step towards reducing the costs and consequences of crises in Iran and countries with similar conditions and have a significant impact on saving human lives in emergency situations.

Keywords: Management Information Systems, Models (Theoretical), Earthquakes.

1. Introduction

The increasing number of natural disasters in the world and their expansion and severity have led to numerous efforts to cope with challenges and improve activities that are related to crisis and crisis management[1]. In critical situations and in order to effectively manage them, people need information that comes from various sources, and it is crucial to have the well-timed and correct data with logical representation to respond and take necessary action[2]. Practitioners and researchers in the field of crisis management believe that the proper use of information and communication technology can be effective in collecting, disseminating and accessing the information needed in times of crisis, and improve all phases of crisis management and the critical

communication cycle according to the needs of different teams[3].

Geographic information system is one of the technologies that can be widely used by teams involved in crises [4-6]. Crises occur in a specific geographical area, and their effects are often location dependent and geographically distributed [4]. A lot of data, information, and knowledge that underline critical decision-making in various phases of crisis management are geographical in nature[7]. The use of GIS technology will bring unique benefits such as a better perception of the interactions of environmental, area-level, social, psychological and sociodemographic influences on physical activity of the target community[8]. This approach can play an effective role in managing natural hazards such as earthquakes, heavy snowfall or avalanches, and human hazards such as aerial bombardment, bioterrorism, and chemical and oil spills. In such cases, most of the victims are trapped and the search and rescue operation depends on determining their location.

Mobile technology can also be a good option for communicating between different crisis management teams [9, 10]. Crisis response teams are also dynamically formed on an ad hoc basis, based on the situation. Their members may work together at the same or different places or at the same or different times[11]. Some members may be settled in stable environments, while others constantly on the move[4]. Crisis managers should be able to facilitate the flow of information between their members with the support of technology, regardless of how the teams are combined. Back-end systems connected to mobile phones have the potential to provide a platform for empowering automated, portable, pre-programmed services, which can be useful for decentralization of health care, and health information systems[8]; And improve coordination between search and rescue teams, pre-hospital emergencies and command centers.

During crises, after finding the victims, providing health services is vital. To do so, electronic health records can effectively provide the needed information for reliably delivering emergency medical services. These records provide clients with access to vital information when needed and are essential for emergencies and crises [12-14]. From the clinical viewpoint, in order to provide quality care, it is essential to access the integrated health information of patients which is collected at the point of care to ensure the freshness of time-sensitive data[15]. This information can minimize the error of commission and omission at the point of care as a key safety advantage for victims[16].

The above are some examples of the application of information technology and information systems in crisis management, but in order to apply the information systems and information technology in effective crisis management, the role of information systems architecture must be considered because the design of information systems architecture has a decisive role in the failure or success of these systems.

The information system architecture generally identifies three distinct aspects of the system and defines them as three sub-architectures[17, 18]:

- *Informational or Data Architecture* determines the data-elements that support the business workflows.
- *Application Architecture* describe applications needed for business support and information management.
- *Technological Architecture* determines the key technologies used in the implementation of applications and the infrastructures that create an environment for information system deployment.

Choosing the right architecture for designing a crisis management information system can meet the information needs in all of the crisis management phases and

crisis communication cycle according to the needs of stakeholders.

Considering the useful applications that information and communication technology can have in effective crisis management, this study was conducted with the aim of providing an architectural model of crisis management information system in a way that it can be used in earthquake-prone countries such as Iran or in the face of other natural disasters during which the victims are trapped and need help.

2. Materials and Methods

2.1 Study design

This study was of applied and qualitative nature and was performed in two stages. In the first stage, crisis management information systems in China, India, Japan, Turkey, Romania and Germany were studied, using electronic resources and digital libraries. Data were collected using a data extraction form that was validated by three management information systems experts and two crisis management experts. The method of analysis at this stage included extracting and categorizing the features and architectural aspects of the crisis management information system in terms of informational content, applications and technological requirements in them. In the second stage, using the interview method[19], the information and software facilities required by the response teams in dealing with the crisis were extracted. After matching the findings of this stage with the findings of the first stage, a preliminary model of crisis management information system architecture including three aspects of informational content, applications and technological requirements, was prepared and validated using Delphi technique and focus group[20]. Fifteen key experts participated in the first and second Steps of Delphi, and twelve of them were in the third step. The data of the first stage were analyzed using content analysis and the second stage was analyzed by descriptive statistics.

2.2 Study population

In the first stage, the study population included printed and electronic copies available through libraries and databases, government reports and documents, Ministry of Health, Red Cross and crisis management agencies' websites in selected countries. In the second stage, the statistical population included crisis management specialists, experts on management information systems and staff with experience in Red Crescent, Emergency Medical Service (EMS) and Search and Rescue (SAR) teams and Crisis Management Center in Iran. Sampling was performed according to the non-random targeted type.

3. Results

Characteristics of Crisis Management Information Systems

Existing studies on crisis management information systems in selected countries are reviewed and their general specifications are summarized in Table 1.

Table 1. Crisis management information system (CMIS) specifications in selected countries

System specifications	Country					
	China	**India**	**Japan**	**Turkey**	**Germany**	**Romania**
Sys. Name	ISNDM	NDMICS	PHOENIX	AFAYBIS	deNIS II plus	SIMSU / EMIS
Authority	Ministry of Human Affairs	Ministry of Home Affairs	Minister of State for Disaster Management	Ministry of Interior	Ministry of Interior	Ministry of Interior

Crisis Management Phase(s)	All	All	Response and Recovery	All	Preparedness and Response	Preparedness, Response and Recovery
Application(s) Type	Desktop	Desktop & Mobile	Desktop	Desktop	Desktop & Mobile	Desktop & Mobile
Language(s)	Chinese	Hindi and English	Multilanguage	Multilanguage	German	Romanian and English
Financial supplier	The World Bank	Government & World Bank	Government	The World Bank	Government	The World Bank
References	[21, 22]	[23, 24]	[25-29]	[30, 31]	[32-34]	[35, 36]

The results obtained regarding the informational architecture in these systems show that the data within them can be divided into two major categories (Table 2). The first category is data generated before the onset of the crisis and includes data related to existing risks, coping capacity and vulnerability of the community, and the second category is data generated during or after the crisis and shows the impact of the crisis and the resources needed to manage it. The results for analysis of data-elements which used in crisis management information systems in selected countries are shown in Table 3.

Table 2. Proposed modules and components in literature for CMIS from informational aspect (categorized into pre- and post-crisis data)

Category	Module	Component	Description
Pre-Crisis	**Baseline / Basic Info.**	Demographic data	- Includes the statistically socio-economic information.
		Building typology	-Refers to the classification of buildings by the similarity of their use into groups such as hospitals, schools, shopping centers and etc.
		Transportation network	- Includes the knowledge of a spatial network and define a platform that supports the moving of vehicles or the flow of products.
		Critical facilities	-Include structures that, has the potential to cause serious disruption of vital socio-economic activities if it is destroyed or damaged (such as shelters, police, fire stations, hospitals and etc.)
		Supply lines	-Refers to the routes which goods and equipment are transported to the first responders during a crisis.
	Risk Reduction Info.	Historical Data	-The time series data or historical facts about earlier disasters.
		Mitigation Data	-Includes related information of disaster risk reduction maps, plans, programs and strategies.
		Educational material	-Educational content used to raise public awareness and skills of respondents.
During & Post-Crisis	**Resource Info**	Human	-Includes information of volunteers and organizations (civic agencies, NGOs, etc.) Who are involved in the crisis management cycle.
		Material and equipment	- Includes logistical support information such as emergency or transportation vehicles, construction tools, supply or medical equipment, personal supplies, food, etc.
		Camp and shelter	-Includes information such as location, number and capacity of provided camps and shelters.
	Stricken people's Info	Missing persons Registry	-The identities of those reported as missing person.
		TDPs Registry	-Information of temporarily dislocated people.

Table 3. Summary of data groups in selected countries

	Country					
Data Group	**China**	**India**	**Japan**	**Turkey**	**Germany**	**Romania**
Baseline / Basic Info.	Yes	Yes	Yes	Yes	No	No
Risk Reduction Info	Yes	Yes	Yes*	Yes	No	Yes
Resource Info	No	Yes	Yes	Yes	Yes	Yes
Stricken people's Info	No	No	No	No	Yes	No
References	[22]	[23]	[27]	[31]	[32, 33]	[35]

* Only Includes historical data

The results of the analysis of the present studies on the applications of crisis management information system show that there are many differences in the scope of operation and functional requirements of these systems. The various applications were obtained by reviewing the studies and analyzing the systems listed in Table 1. These applications are grouped into three main modules and their related components. (as shown in Figure 1). The existence of each of these modules or their related components in each system depends on the needs of stakeholders and the system's functional specifications. Figure 1 shows that crisis management information systems can be applied in three main modules: administration, operations, and prevention. Studies show that among these modules, the prevention module has received less attention and the focus of most existing information systems is on the operation module, which is related to the response and recovery phases in the face of a disaster.

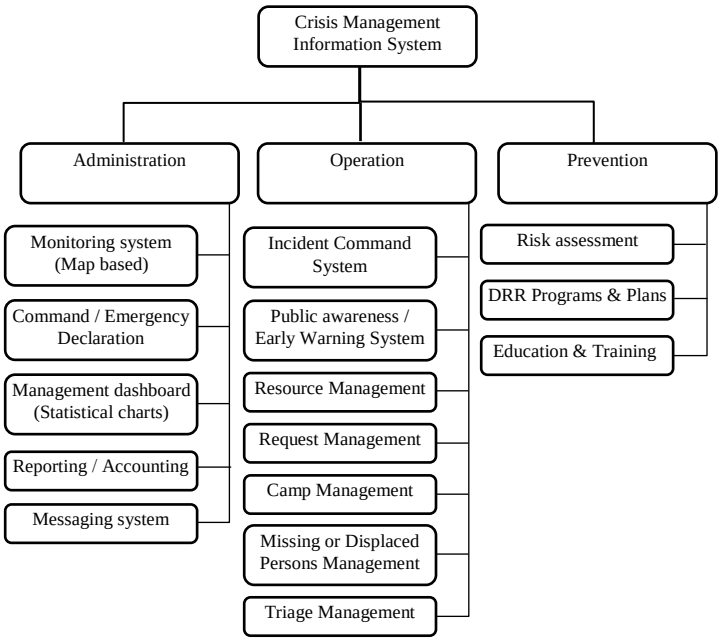

Figure 1. Proposed modules and components in literature for CMIS from application aspect

The prevention module seeks to reduce the risk by creating various simulation models for potential hazards. It starts with risk assessment and after performing the necessary analyses regarding the severity of the risk, the degree of vulnerability and the probability of occurrence of the risk, possible plans and programs are created to reduce the damage caused by various disasters. Also, educating people in general or professionally can have a great impact on reducing the amount of these damages.

Operation module is the main module of the crisis management information system used in case of disaster by operational managers. This module includes incident command system (ICS), early warning system (EWS) to provide warning information about hazards and vulnerabilities, resource management based on requests received from field operators, camp management, registration of missing or displaced persons by operational teams, and triage management of casualties.

The administration module allows crisis managers to view the current catastrophic situation by using a map-based monitoring system. It also provides the ability to declare a state of emergency, Access information that is useful in decision making (via management dashboards), get report and exchange messages with responsive organizations in the face of crisis.

The results of the analysis of the studies in Table 1 from the aspect of technological requirements of crisis management information system show that various information and communication technologies have been used according to the functional requirements of these systems in different countries. These technologies are categorized into two main modules called information tools and information infrastructures, which are summarized in Figure 2.

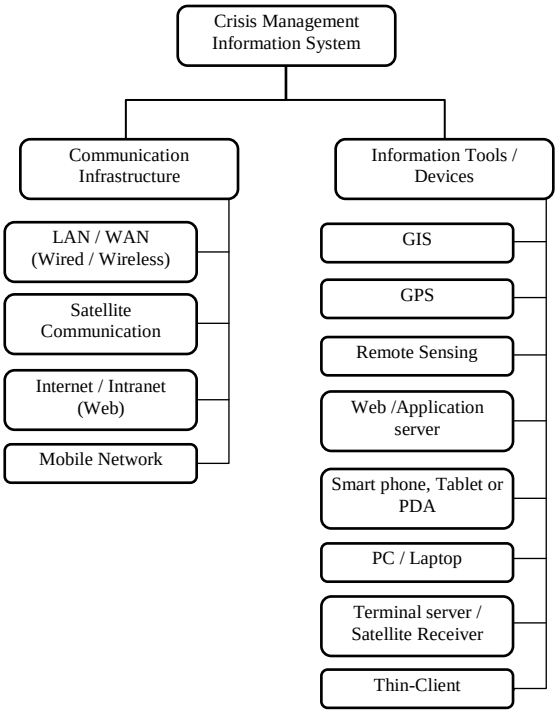

Figure 2. Proposed modules and components in literature for CMIS from technological aspect

Architectural Model Design

In the first step, the results of matching the findings of the first stage with the findings of interviews with key experts, is represented in the form of a conceptual model of crisis management information system architecture include three aspects of information, application and technology (Table 4).

Table 4. Recommended modules and components of CMIS architecture in the first round of Delphi

Aspect	Module	Component
Informational	Baseline Info.	Demographic data
		Critical facilities
		Supply lines
		Transportation network
		Electronic Health Records (EHR)
	Resource Info	Human
		Material and equipment
		Camp and shelter
	Stricken people's Info	Missing persons Registry
		TDPs Registry
		Casualty persons Registry
Application	Administration	Monitoring system (Map based)
		Management dashboard (Statistical charts)
		Messaging system
		Reporting / Accounting
	Operation	Incident Command System
		Logistics Management System
		Requests Management System
		Affected people Management
		Camp Management
		SAR Assistant
		EMS Assistant
Technological	Communication Infrastructures	Local area network (LAN)
		Internet / Intranet (Web)
		Mobile communication network
	Information Tools / Devices	Desktop or Laptop computers (Terminal for browsing and inputting)
		Smartphone and tablet (cellular devices)
		Application and Web servers for the system
		Geographic Information System (GIS)

In the second step, the Delphi technique was used and in general, 7 modules and 28 components were agreed upon by key experts with a consensus of more than 75%. All three aspects of information, application and technology were confirmed in the proposed architectural conceptual model. The only change was the three components including *"Critical facilities"*, *"Supply lines"* and *"Transportation network"* as a subset of the *"Baseline Info"* module. They merged and the combination was named as a component called *"Geospatial data"* and a description column was added to the model to explain each component.

Table 5 shows the changes and modifications recommended by the panel in relation to the proposed model.

Table 5. Conceptual model of crisis management information system architecture

Aspect	Module	Component	Description
Informational	Baseline Info.	Demographic data	- Includes the statistically socio-economic information.
		Geospatial data	-**Critical facilities**: Includes related information of critical structures such as shelters, police, fire stations, hospitals and etc. -**Supply lines**: Includes information of the routes which goods and equipment are transported to the first responders during a crisis. -**Transportation network**: Includes the knowledge of a spatial network and define a platform that supports the moving of vehicles or the flow of products.
		Electronic Health Records (EHR)	-Includes citizens' summarized health record information for use in critical situations.
	Resource Info	Human	-Includes information of volunteers and organizations (civic agencies, NGOs, etc.) Who are involved in the crisis management cycle.
		Material and equipment	-Includes logistical support information such as emergency or transportation vehicles, construction tools, supply or medical equipment, personal supplies, food, etc.
		Camp and shelter	-Includes information such as location, number and capacity of provided camps and shelters.
	Stricken people's Info	Missing persons Registry	-The identities of those reported as missing person.
		TDPs Registry	-Includes Information of temporarily dislocated people.
		Casualty persons Registry	-Includes information on dead and injured people.
Application	Administration	Monitoring system (Map based)	-In order to coordinate the involved teams by observing the crisis zone and monitoring the activities of operational forces.
		Management dashboard (Statistical charts)	-Provide information such as the amount of damages, volume of the requests and the status of available resources in the form of graphic charts to improve situation assessment and decision making in crisis situations.
		Messaging system	-Intended for Command or Emergency Declaration by the Crisis Management Center and exchanging messages with relevant organizations.
		Reporting / Accounting	-Intended for preparing reports in the form of statistical tables.
	Operation	Incident Command System	-Intended for command and coordination within the organization.
		Logistics Management System	-To assist in estimate the required volume of foods, drugs, blood products, equipment and manpower.
		Requests Management System	-Stores requests and messages from operational teams for regular support processes.
		Affected people Management	-Inserting and organizing the details of the dead, injured, missing and displaced people.
		Camp Management	-To ensure the protection of displaced populations and their rights, effectively and efficiently.
		SAR Assistant	-Intended to determine the possible location of the victims to assist in the search and rescue operation.
		EMS Assistant	-Intended to retrieval the citizens' summarized EHR for EMS teams in Crisis time.
Technological	Communication Infrastructures	Local area network (LAN)	-LAN in Ministry of Interior buildings
		Internet / Intranet	-Communications to access the CMIS from relevant team and organizations (Response agencies & NGOs).
		Mobile communication network	-Applied to enable the use of location-based service (LBS) and to give operational teams access to the CMIS.
	Information Tools / Devices	Desktop or Laptop computers (Terminal for browsing and inputting)	-To browse the status of crisis and enter inspection data for facilities.
		Smartphone and tablet (cellular devices)	- Cellular devices to read and write information on CMIS through the mobile apps.
		Application and Web servers for the system	-Servers for the Facility CMIS.
		Geographic Information System (GIS)	-Serves as an integrated GIS system that enables the Ministry of Interior and relevant agencies to work on the same drawing and applied the LBS through the mobile telecommunication system.

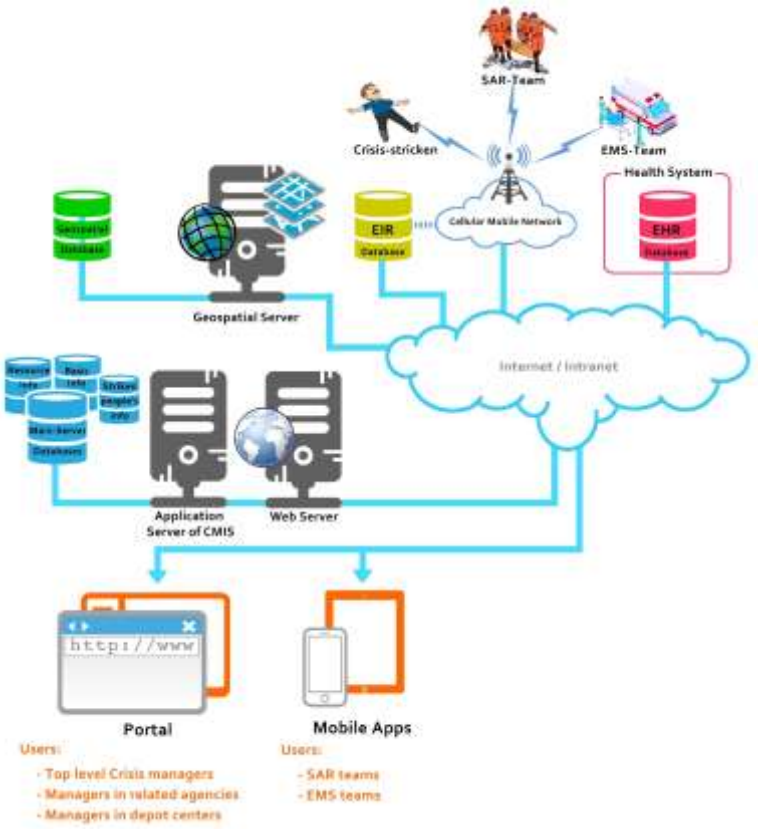

Figure 3. Crisis management information system architecture diagram

The software architecture was designed as client-server. The proposed information system has two sections: (Figure 3)

- **Server section**: includes an application server that is responsible for the core of the system and communicates between clients and the database through a web server. The database used is configured on the application server. It is also a geo-server connected to the main server and supports services related to geo-maps and location.
- **Client section**: includes a web-based portal (for crisis managers and depot-centers[1]) and mobile software (for operational teams)

The server's task is to manage the system databases and fetch the required information from other systems such as Geographic Information System (GIS), Electronic Health Record System (EHRs) and HAMTA[2]or Equipment Identity Register (EIR) Database. This section also provides the necessary warnings to the user in case of not receiving proper feedback from other systems. The server-side architecture model is Model-View-Controller (MVC) multilayer architecture.

The client's task is to provide access for all types of users to use the software features of the system, and according to the mobility of users in emergency situations, two types of software are considered, which include a web-based portal and a mobile application:

Web-based portal is for users who are usually stayed in relatively stable environments and is available through any device (such as desktop computer, laptop, tablet or mobile) that can connect to the Internet. So, it should be designed with the

[1] Depot center: a place for the storage of large quantities of equipment, food, or some other commodity

[2] HAMTA is the name of an intelligent communication equipment management system in Iran that stores information about the ownership and IMEI number of cellular devices of all mobile network users.

ability of Cross-browser compatibility and be responsive. Portal users include top-level crisis managers, operations managers in related organizations (such as the Red Crescent, fire department and Emergency Medical Management Center), and logistics managers in depots of medicine, equipment and blood products. The access level of portal users to the functions and information of system can be defined by the system administrator. The most important functions of the portal are assistant tools for "situation assessment", "decision making", "coordination and cooperation between operational teams" and "logistics and supply management."

Mobile application is for users who are constantly on the move according to the type of mission and consists of a lightweight application that can be installed on smartphones or tablets equipped with mobile SIM cards. Its users include members of the SAR team and EMS team. Users can send their reports, messages and requests to the relevant managers using the mobile software and receive the crisis management center's messages in real time. The most important Functions of the mobile software in this system are locating the crisis victims to assist in search and rescue operations and viewing the summary of the citizens' electronic medical records by the pre-hospital emergency medical service team to improve the provision of medical services to the victims.

The communication network used at the relevant ministry level can be a local network or intranet within an organization that is connected to the Internet and other organizations and users are connected to the system through the Internet. The mobile network is also designed to communicate with users who are constantly on the move. The location of clients and operational teams is identified and displayed on a map using a location-based service and the location of mobile telecommunication network terminals, and GIS.

Information in the system includes demographic data of the affected area, geographical location data of clients and operational teams, summarized electronic health records, resource-related data such as organizational information of users and operational teams, data related to operational team requests, data on casualties such as missing, dead, injured and displaced, and citizens' international mobile ID information. In designing the system, full compliance with the

APIs of GIS, electronic health record generating system and intelligent communication equipment management system has been seen.

4. Discussion

The principal finding of this study represents an architectural model of crisis management information system that supports the operational teams specially for search and rescue and emergency medical services. In the process of finding trapped victims and Relief them, In the face of natural disasters such as earthquakes.

Most of the crisis management information systems are designed to be coherent with the incident command system’s organizational architecture, and do not cover the crisis management functions outside the command and control center [30-32, 34, 35].

The difference between the architecture of the crisis management information system proposed in this study (presented in Figure 3) and the architecture of other existing systems is in supporting the management tasks outside the command and control centers, such as rescue operations (SAR team), pre-hospital emergency operations (EMS team) and the process of supply and distribution of materials and equipment (depot centers) which is done through providing and sharing of vital information required by these teams.

This information, which is shared with the aim of reducing human casualties and maximizing the use of available resources,

includes the location of affected persons to expedite search and rescue operations, summarized electronic health record of affected persons to improve the provision of emergency medical services, and information related to the essential requests of the operational teams for effective supply and distribution of materials and equipment by depot centers.

As above mentioned, in this architecture, special attention has been paid to the functions outside the command and control center, such as the SAR and EMS teams. Due to the fact that these teams are often on the move and do not have a specific location, mobile technology has been used to connect them with the Crisis Management Center. The continuous communication of these teams with the Crisis Management Center and related organizations is important because their activities are directly related to saving the lives of the victims. From the moment of the catastrophe for 72 hours is the golden time to save the lives of the victims. For this reason, it is important that on this occasion effort be made to save human lives in a fast, coordinated and effective way[37].

The most important expectation from the rescue team is to find the missing persons and release them as soon as possible. This architecture is designed in such a way to make it possible to locate the missing persons for the rescuers in the scene of the accident through the mobile application so that the search and rescue operations can be done more quickly and accurately. After finding the victims, it is time to provide health services. At this time, a significant number of patients in a certain unit of time need to receive medical care, one group of people who are injured at the time of the disaster and the other group of people who are already sick and need specific medication and medical equipment[38]. Electronic health records can be effective in providing these services optimally. Because their information can minimize the error of commission and omission at the point of care as a key safety advantage for victims. [16]. For this reason, in the architecture of the crisis management information system, the connection with the electronic health record generating system is considered so that the EMS team can have access the summary of the electronic health record of the victims through the mobile application.

Also, the architecture used effectively supports the activities of logistics and supply managers in depot centers. The operational teams send their requests to the Crisis Management Center and each of the depot centers, according to the access-level that the Crisis Management Center has provided for them, can view requests online and take appropriate action to provide the desired materials or equipment. In parallel with this process, the Crisis Management Center monitors the process of supplying requests and takes the necessary measures to supply the non-suppliable materials and equipment by the depot centers. Therefore, the requests of the operational teams will be answered effectively, and they can fulfill their mission in a desirable way.

Against the strengths of any architecture, there are weaknesses or threats that must be planned to overcome. In the present architecture, the Mobile Communication Network is considered as the communication platform of the operational forces with the Crisis Management Center so that the destruction of the base transceiver stations (BTS) of this network during earthquakes or similar catastrophes can lead to the failure of the operational forces communication with the crisis management center. There are several solutions to this problem. For example, the Mobile Communication Network's stations can be made resistant against large earthquakes, or portable stations can be used to overcome the communication failure in an emergency. Also, the distribution of wireless internet in the crisis zone can be another solution to solve this problem.

5. Conclusion

The four phases of crisis management depend on information that comes from various sources, and it is crucial to have the well-timed and correct data with logical representation, to the teams in need so that they can make appropriate decisions and carry out their mission well. The use of information technology and information systems in their various forms can provide a variety of information that is needed in the face of crises. However, it should be noted that the architecture of information systems has a direct impact on the performance of these systems in critical situations. The use of appropriate architecture in the design of crisis management information system can be an effective step to reduce costs and consequences of crises in Iran and countries with similar conditions and have a significant impact on saving human lives in crisis.

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Conflict of interest

The authors declare no conflict of interest.

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