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A comparative study of disaster management information systems

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Abstract

Purpose – Disaster management information systems (DMISs) have been proposed in different parts of the world for effective response to a disaster. The purpose of this paper is to: compare design approaches of these DMISs; examine similarities in the design of databases and communication infrastructure; and draw conclusions. Based on the examination of the studies, future opportunities have been identified and discussed.
Design/methodology/approach – The studies in the available literature on the designs of automated DMISs have been reviewed in the presented paper to identify similarities in design premise, conceptual design and design considerations.
Findings – The examination of the available studies indicates that the research on DMIS has increased significantly in different countries of the world since 2004. Data of baseline information and available resources are required by most of the presented studies, as these data are necessary for effective response to a disaster. The communication infrastructures suggested include local area network, wide area network and satellite communication for better coordination between the responders and different relief agencies at different locations. The connectivity to these networks is possible through Ethernet, Wi-Fi, general packet radio service or satellite.
Research limitations/implications – Although the research on DMIS has increased significantly over the last one decade, the studies are still few in numbers. Similarly, only few of the proposed systems have been developed and tested during a real disaster.
Practical implications – The presented review of available studies provides a holistic view of the proposed DMISs which could be useful to the disaster management authorities.
Originality/value – The paper provides valuable information on the differences in the proposed DMISs. This can help in identifying the gaps for future improvements for increased effectiveness of a DMIS. The future opportunities have also been identified in the presented paper and are discussed.

Keywords Communication, Disaster, Mitigation, Information system, Response, Hurricane

Paper type Research paper

Introduction

Human response to natural hazards has been a subject of intense investigation and study. These hazards have proved to be the most difficult enemy of mankind as they are able to cause destruction on a large scale close to human settlements. The events of natural disasters may be identified by excessive magnitude, frequency or duration (Arey and Baumann, 1971; Bolt *et al.*, 1975). Human activities, in some cases, also influence the frequency and severity of natural hazards (Shield, 2004). Natural hazards are of either geological or atmospheric origin. These include hurricanes, volcanoes, floods, tornados, typhoons, famine, fires, landslides and earthquakes. Some of these hazards may be interconnected with each other. For example, earthquakes may cause landslides.

The study of human history indicates that the ability of natural hazards to cause destruction is partly due to lack of preparedness of human beings to mitigate the effects of these hazards. A hazard needs not to become a disaster. Disaster preparedness and mitigation prevent a hazard from turning into disaster which can reduce the efforts for reconstruction and rehabilitation of the affectees. Nevertheless, in many cases, this is not possible to avoid disasters completely. As a result, disasters happen and cause loss of life

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and property, disruption of services, hunger, injures and diseases (Vanholder *et al.*, 2001; Zhang *et al.*, 2002).

Disaster management (DM) deals with both the mitigation and consequences of disasters. The former refers to pre-disaster preparations whereas the latter is related to post-disaster response. Aspects of planning to deal with a hazard and to avoid associated risks (Haddow and Bullock, 2004) are parts of pre-disaster mitigation. Post-disaster response is required to assure prompt and appropriate assistance to the victims of disaster, and to achieve rapid and effective recovery from a disaster.

Post-DM operations are complex (Bigley and Roberts, 2001) and are information-intensive (Davenport and Prusak, 1998; Meissner *et al.*, 2002; De Bruijn, 2006) as these involve different stakeholders (Comfort and Kapucu, 2006). An effective response to a disaster requires not only a large variety of information for the decision makers but also its rapid flow and better coordination of activities. Good quality information improves the effectiveness of DM operations and avoids dangers to the responders and victims (Helsloot, 2005; Fisher and Kingma, 2001; Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, 2004; Turoff, Chumer Walle and Yao, 2004; Hassan *et al.*, 2011). The coordination is needed both within the DM agency and between different agencies at several hierarchal levels (Auf der Heide, 1989). Since these operations involve severe time pressure and high uncertainty (Argote, 1982; Smith and Hayne, 1997; Ganeshkumar and Ramesh, 2010), improved coordination between relief agencies and workers can help in optimising the resources to carry out relief activities efficiently.

The use of computing technology has increased in DM similar to other fields (Borkulo *et al.*, 2005; Dorasamy *et al.*, 2011; Dorasamy and Raman, 2011; McEntire, 2007; Raman *et al.*, 2011; Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, 2004; Turoff, Chumer Walle and Yao, 2004; Wattegama, 2007; Ariyabandu, 2009; Tad and Janardhanan, 2014). The availability of advanced hardware and software capabilities allows a swift response to any emergency situation in reasonable time and cost. The use of an integrated system to connect relief agencies together and to provide them ways to exchange and process information in real-time can enhance effectiveness of emergency response. The advancement in technology has made it possible to achieve both these objectives by transferring its benefits in the area of DM. As a result, the need of development and use of automated systems to manage disasters have attracted the attention of researchers all over the world (Stephenson and Anderson, 1997). Efforts have been carried out to provide reliable and coordinated response to a disaster using support networks and physical facilities which could be kept functional in a disaster situation with the help of modern technology (Kunreuther and Lerner-Lam, 2002; Mork, 2002).

DM refers to the process of acquisition, management and utilisation of disaster information in order to carry out disaster relief operations (Zhang *et al.*, 2002). The modern technologies provide an effective tool for the development of a DM information system (DMIS). A DMIS is a computer database that enables the responders to share and use real-time information during a disaster (Atteih *et al.*, 2010; Lee *et al.*, 2012; Murphy and Jennex, 2006). Considering the advantages that an automated DMIS can offer, these systems have been proposed in different countries of the world. Data integration, data mining and multi-criteria decision making are the essential components of an automated DMIS (Peng *et al.*, 2011). The data integration provides a link between the modules of data sources and data analysis. The data mining assists the users in the management of pre- and post-disaster information. The multi-criteria decision making is used to dispatch emergency resources and to evaluate effective alternative solutions. This paper reviews the literature on the strategies to design these components. The approach used by different researchers to design these aforementioned components, and the system development and management schemes have been compared. Based on this comparison, gaps in the proposals of DMISs have been identified and future opportunities for improved effectiveness of DMISs in DM operations have been discussed. Although the examined studies differ by region, the technological advancements are universal which makes the comparison possible. Valuable information can be obtained where differences are found.

Strategies for disaster risk reduction (DRR)

DRR refers to the identification and assessment of risk of life losses and property damages and the efforts to protect people, infrastructure and economic and social resources from the effects of disasters. The notion encompasses all activities related to DM, preparedness and mitigation. DRR provides a pathway to sustainable development by increasing resilience of individuals and communities. The factors responsible to changing a hazard into disaster include poor built environment, poor socio-economic conditions of a society and governance issues. As a result, DRR demands a multi-prong approach which requires involvement of different stakeholders and sections of a society such as individuals, communities, government, non-governmental organisations (NGOs), civil society and private sector. In view of the disastrous consequences to the sustainable development due to a disaster, DRR has been made a policy priority for the governments all over the world and a number of international policies and frameworks have been developed. These include Yokohama Strategy and Plan of Action (1999–2000), Hyogo Framework of Action: Building the Resilience of Nations and Communities (2005–2015) and African Regional Disaster Risk Reduction Framework and its Plan of Action.

The role of government is crucial in providing and/or implementing effective institutional framework for DRR to ensure sustainable development. The framework provides a basis for the development of policies for DRR programme which improve the effectiveness of DRR agenda with the help of the aforementioned stakeholders and multi-disciplinary approaches. The overall DRR strategy is based on vulnerability and risk assessment for different disasters and capacity building to mitigate these disasters. Carter (1991) identified the following means for disaster mitigation: provision of building codes, land-use planning, government grants and incentives for disaster resistant construction, training and education, public awareness and strengthening of social structure. In addition to these, an early warning system and considerations of gender behaviour in the DRR agenda (Ariyabandu, 2009) are the effective tools of risk reduction.

History of DMIS

The research on the development of automated information systems in different fields started during the 1950s (Lewin, 1958). The computing technology has also been in use for DM applications for some time. For example, Office of Emergency Preparedness (OEP) in USA developed Emergency Management Information System and Reference Index (EMISARI) during the 1980s to deal with the natural and man-made disasters (Macon and McKendree, 1974; Macon *et al.*, 1975; McKendree, 1977, 1978). The design of EMISARI was based on a group communication process (Hiltz and Turoff, 1978/1994, 1993; Ruben, 1992; Turoff, 1991). It followed the concepts of Delphi method (Linstone and Turoff, 1975) to integrate people and data into a single database which could be dynamically changed by non-technical administrators (Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, 2004; Turoff, Chumer Walle and Yao, 2004). EMISARI allowed up to 300 users throughout USA to coordinate during an emergency and to utilise the available data urgently (Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, 2004; Turoff, Chumer Walle and Yao, 2004). Nevertheless, this was a static information system (Hiltz and Turoff, 1978/1994) in that it was unable to allow management of resources in real time during a disaster.

The need of an integrated communication system was realised long time ago (Smith and Hayne, 1997). A technical cooperation project in Latin America and the Caribbean entitled

SUMA (PAHO, 1998) was started in 1992 to increase the capacities in these countries to effectively manage information of the incoming relief goods. A computer software entitled Disaster Inventory System (DesInventar) (Corporación, 1994) was developed to connect nine countries of Latin America together for building databases of loss and damage, and the effects of disasters (using existing data, newspaper and institutional reports) in these countries.

Lakovou and Douligeris (2001) proposed information management system for hurricane disasters (IMASH) which was implemented using Oyster (Collins *et al.*, 1997). IMASH was similar to oil spill information management system proposed by Douligeris *et al.* (1995). Nevertheless, IMASH was designed specifically for hurricane DM, contingency planning and preparedness and post-disaster restoration activities.

Based on the experiences learnt from the use of EMISARI and the response failure events as reported in the literature, Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan (2004), Turoff, Chumer Walle and Yao (2004) carried out a study to propose the development of a virtual command and control centre to conduct disaster response operations with the help of a multi-level human network. These authors proposed a framework for the design and development of a comprehensive Dynamic Emergency Response Management Information System using the design basis of EMISARI and design concepts reported in the technical literature. Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan (2004), Turoff, Chumer Walle and Yao, (2004) considered an exhaustive set of design premises and principles in the proposed framework of DMIS based on five essential concepts of a group communication system; these include system metaphor, human role identification, notification, context visibility and hypertext. The year 2004 marks a rapid increase in the research on the development of DMISs across the globe, as discussed in the forthcoming sections.

The first application of DMIS in South Asia started with the development of Sahana in Sri Lanka in the aftermath of the 2004 tsunami in the Indian Ocean (Ariyabandu, 2009). Sahana is a free and open source computer programme. The use of hypertext preprocessor (PHP) as a programming language in Shahna provides compatibility with the geographically referenced data on the geographical information system (GIS) platform which greatly facilitates response to a disaster. This software has been recognised internationally and has received several awards (Careem *et al.*, 2006). The details of a number of available and proposed systems in different countries have been discussed in the forthcoming sections.

DM information systems

The increased importance of a comprehensive DMIS to meet the functionality requirements of planning and conducting DM functions was realised after the events of 9/11 attacks on twin towers in USA (Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, 2004; Turoff, Chumer Walle and Yao, 2004). As a result, there has been a notable increase of research in DMISs since 2004 which appears to be occurring in parallel in different countries. This is owing to the reason that it is not possible to design a generic system which could satisfy needs of all countries for all disasters (Dorasamy and Raman, 2011).

A DMIS is a software package which can perform networking, scheduling, and data resource analysis and management during a disaster to enable accelerated response and recovery of the affectees. The overall design principle of a DMIS is based on development of software that provides the required functionality. The structure of DMIS software involves coordination of humans involved in the response by allowing various levels of command and control using a communication system. The developed application requires the use of computing technology for the operation of software which can easily be met with the availability of present day hardware such as personal computers, laptops, personal digital assistants (PDAs), smart phones and wireless gadgets. The system can be applied in all disaster situations such as post-earthquake disaster, fires, bomb blasts, hazardous material spill, transportation interruptions, etc. It, nevertheless, requires that adequate training and experience is provided to the involved personnel.

The available studies on DMIS from different parts of the world that are examined in the presented paper are summarised in Table I. The studies in Table I have been organised in the same chronological order as they appeared in the literature. The method of analysing these systems includes a comparison of available features and their functionality. The analysis of these studies indicates large variations in their scope and functionality requirements. Different modules and their components which are found from the analysis of studies in Table I are illustrated in Figure 1. The availability of any of these is dependent on the functionality requirements of the proposed system and varies from one system to the other. It is seen in Figure 1 that DMISs can be divided in two categories: disaster inventory system (DIS) and information management system. DIS is comprised only a data inventory module in which a disaster database is stored. This database consists of baseline data, information of resources, historical records of disasters, missing person's registry, information of response agencies and response facilities.

A maximum of five modules have been suggested for a typical DMIS. These include data inventory, mitigation, administrative control, response and recovery and communication infrastructure. Of these (except mitigation), four have been proposed in the majority of the studies included in Table I. A review of the studies in Table I indicates that most of these focus response and recovery (R and R) phase of an on-going disaster; only few consider pre-disaster mitigation phase. Mitigation process may start with hazard scenario analysis using available simulation models for different hazards. Hazard and risk maps may be developed for an area based on the simulation results. Accordingly contingency plans and DRR strategies may be adopted to reduce the damages associated with different disasters.

Administrative control module is made available only to authorised managers or administrators. This module provides facility of viewing the situation of on-going disaster using monitoring system to an administrator who may declare an emergency.

S. No.	Author	DM Component	Origin	S. No.	Author	DM component	Origin
1.	Corporación (1994)	Response	USA	11.	Tata (2009)	Response	India
2.	PAHO (1998)	Response	USA	12.	Atteih *et al.* (2010)	Response	Saudi Arabia
3.	Kitamoto (2000)	Response	Japan	13.	Ganeshkumar and Ramesh (2010)	Response	India
4.	Lakovou and Douligeris (2001)	Preparedness and Response	USA	14.	Hassan *et al.* (2011)	Response	Malaysia
5.	Meissner *et al.* (2002)	Response	Germany	15.	Dorasamy *et al.* (2012)	Response	Malaysia
6.	Eraslan *et al.* (2004)	Mitigation and Response		16.	Lee *et al.* (2012)	Response	Hong Kong
7.	Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan, (2004), Turoff, Chumer Walle and Yao (2004)	Response	USA	17.	Saeed *et al.* (2013)	Response	Pakistan
8.	International (2005)	Response	Japan	18.	Li *et al.* (2014)	Response	USA
9.	Murphy and Jennex (2006)	Response	USA	19.	EmerGeo (2016)	Mitigation and Response	Canada
10.	Ariyabandu (2009)	Response	Sri Lanka				

Table I.
Summary of examined studies on DMISs

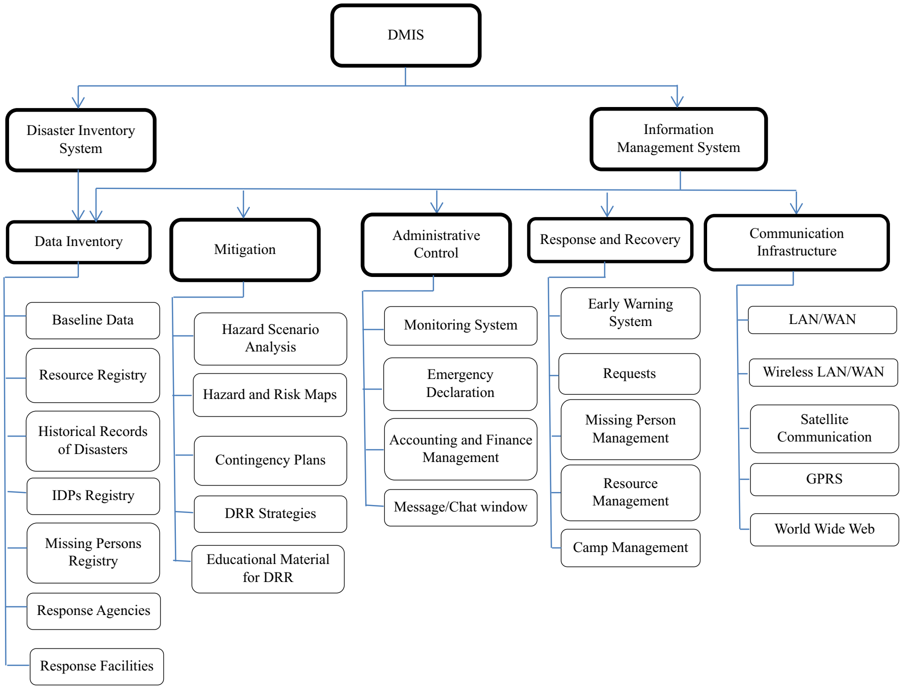

Figure 1.
Modules suggested in literature for DMIS

Accounting and finance management is also carried out using this module. Request for financial aid and resources may be forwarded by the administrator based on a need analysis. A message/chat window may be used for the sharing situational updates among disaster managers.

R and R module is the main module of DMIS which is used during the disaster as it manages the entire response to the disaster. Resource allocation is carried out using this module according to the requests received from the field operators. Missing persons' management and shelter management is carried out according to the data entered by the field operators. Early warning system is also a part of this module which is used to disseminate information on an emerging dangerous situation to enable action in advance to reduce the risk.

Table I also provides the details of main focus of the proposed systems. It is seen in Table I that, while all the studies focus on the response to the needs of the affectees, the studies in the reference Eraslan *et al.* (2004) and EmerGeo (2016) provide modules for pre-disaster mitigation activities. These activities include development of hazard and risk maps of the target areas, and providing education material for DRR (Figure 1). In this respect, EmerGeo (2016) provides the advanced capability of computer simulations to conduct scenario analysis for different types of hazards. Based on these simulations, design of protection against a hazard (where applicable) is carried out by the programme and its cost is calculated. The preparedness module in reference Lakovou and Douligeris (2001) provides contingency plans to deal with hurricane, and information on research and technology development to reduce the level of this hazard.

Further, the systems proposed in references Corporación (1994), Kitamoto (2000) and Tata (2009) are DISs, as opposed to DMIS. As mentioned earlier, a DIS is a database of past and on-going disasters without management functionality (Figure 1). This information is made available publicly through a website or a web portal. The system suggested by

Ganeshkumar and Ramesh (2010) is standalone software which contains databases of response agencies and facilities; the system is limited to finding out the shortest route for the nearest response facility. Saeed *et al.* (2013) proposed a GIS-based web application suitable for Android smart phones which provides the location of response facilities in the affected areas. Although these aforementioned systems are limited in their applications, these have been included here to compare the design of databases in these with those in DMISs.

Finally, the systems proposed in references Corporación (1994), Kitamoto (2000), Tata (2009), Eraslan *et al.* (2004), EmerGeo (2016), PAHO (1998), International (2005) and Lakovou and Douligeris (2001) have been developed and tested during the real disasters. These are available with the trade names of DesInventar, Digital Typhoon, India Disaster Knowledge Network, AFAYBIS, EmerGeo Fusionpoint, SUMA, PHOENIX and IMASH, respectively. A comparison of design of data inventory and communication infrastructure suggested in the studies in Table I has been presented in the forthcoming sections.

Design of data inventory

Data inventory is a basic and essential module of any DMIS. The data required for DM can be divided into pre-disaster data and post-disaster data. The hierarchical structure of the data for the access and presentation of the information in both these categories is illustrated in Figure 2. It is seen in Figure 2 that pre-disaster data consist of baseline data, past records of disasters and the available resources. Post-disaster data consist of available resources, temporarily dislocated people (TDPs) and missing persons. Therefore, the data of available resources are overlapped by both the pre-disaster and post-disaster stages, as these data are continuously updated after a disaster.

The resources may comprise of human and material and equipment resources. Human resources are provided by both the response organisations (civic agencies, NGOs, etc.)

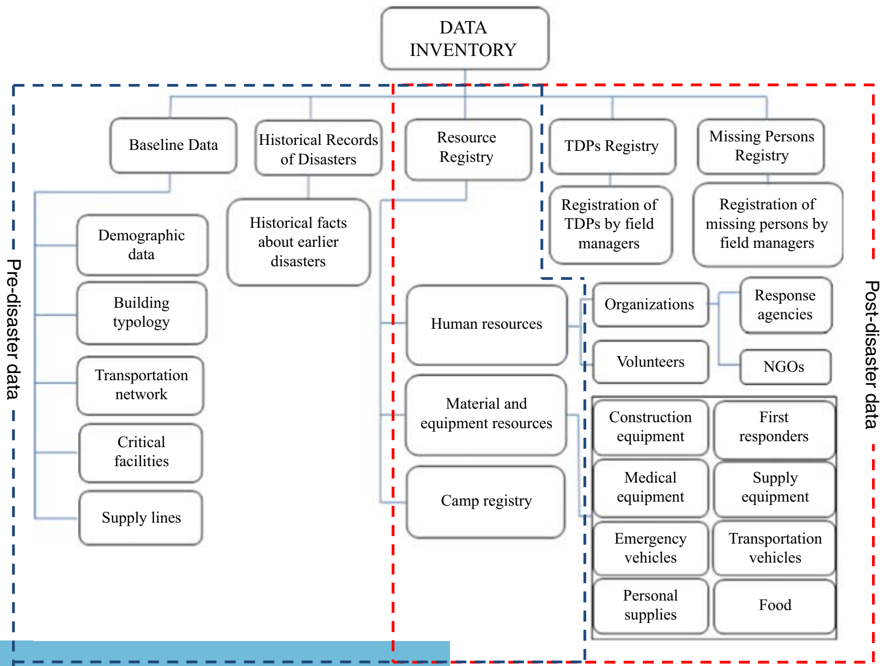

Figure 2.
Hierarchy of pre- and post-disaster data inventory

and volunteers. Material and equipment resources may consist of logistical support such as vehicles, tools, supplies, etc. Resource management is carried out by managing demand and supply for both types of resources using the data available in the data inventory. The demands are those requests for the emergency supplies that are received from the disaster sites.

The design of data inventory is based on the following essential elements.

Data input template: a data input template is a form that is used to collect different data sets as shown in Figure 1. The template provides a user interface whose contents are derived from the logical data structure; this is identified during the analysis stage of the system development using flow diagrams.

Data authentication: data authentication refers the confirmation of the origin and integrity of data as reliable data are essential in a disaster situation. The reliability of data is safeguarded by authenticating the data entry into the system to the authorised entities.

Data format standardisation: data format standardisation transforms the stored data and information into a well-defined and consistent form which is compatible with the scheme of database development. Disaster information may be collected in different forms and order, and spelled differently. It may become out-dated or may contain errors. For example, if data are collected over telephone for entry into the system, spelling variations of names cannot be ruled out. Typing errors are also possible at the time of data entry. The data format standardisation attempts to deal with these issues. Conversion of the input data into a well-defined form and segmenting it into many smaller output fields, allows the linkage process to become more accurate.

Data category analysis: the aim of data category analysis is to organise the data into different categories for their effective and efficient use. A well-planned data classification system facilitates data search and its retrieval. Data classification procedures are used to define those categories and criteria that DMIS will use for data classification. Based on the data classification, security standards (that specify appropriate handling practices for each category) and storage standards (that define the data lifecycle requirements) are provided.

Data redundancy: data redundancy refers a condition in which the same data may be stored in two separate spaces in a single database. This can mean two different fields within the same database, or two different spots in multiple software environments. Data redundancy can occur by accident or deliberately for backup and recovery purposes.

The schematic of data flow in a DMIS is illustrated in Figure 3. It is seen in Figure 3 that different types of data, such as geographically referenced data, demographic distribution in an area, data related to response organisations, available resources and situational updates, are collected independently and are stored in local servers by the authorised personnel using the data input templates. Data authentication is also ensured at this stage. These data are fed to the main server through internet after the data format standardisation is completed. The information collected from various sources is filtered to retain that information which is likely to satisfy the user needs. The filtered information is organised in different categories through indexing, categorisation and linking tools. Of these, indexing plays a critical role in achieving fast and accurate search of correct data at an appropriate time. Linking connects the relevant information with knowledge base related to a specific disaster event. The extracted information can be shown in different forms such as utility maps, evacuation routes from the disaster site, medical and shelter facilities, demographic distribution maps and real-time situation of disaster related damages at a site.

Table II presents the details of data and database type considered in the studies examined in the presented paper. It is noted in Table II that database types have been mentioned in only few studies. In addition, no particular trend appears in Table II in this regard. It is also noted in Table II that most of the studies consider the data of geographically referenced baseline data and available resources which increases the effectiveness of response to a disaster by providing information about alternate routes, distribution of supply lines and buried facilities.

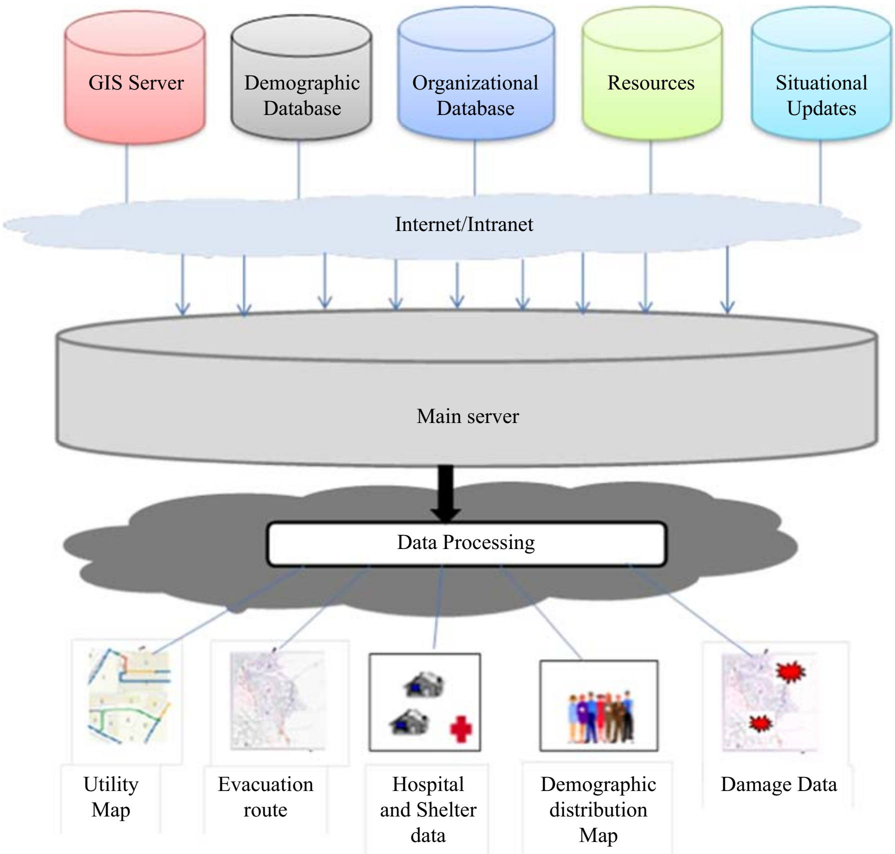

Figure 3.
Flow of information for DMIS

Only few studies have included the modules of historical disasters and natural hazards which are needed for obtaining essential information of the earlier disasters, such as affected area, magnitude, number of casualties and estimated loss. Only the studies in reference Eraslan *et al.* (2004), Ariyabandu (2009) and Tata (2009) have suggested data for shelters. With the exceptions of Ariyabandu (2009), Meissner *et al.* (2002) and Murphy and Jennex (2006), no other study considers the module for missing persons registry. Finally, Ariyabandu (2009) is the only study which requires TDPs registration.

Communication infrastructure design

Communication works as a backbone in DM as it allows quick and effective implementation of the decisions (Eraslan *et al.*, 2004). Reliable and protected communication network is needed for an effective DM system. The network should be inter-operable with those of other organisations. A committed two-way communication system is required for swift response to a disaster which should be cost effective, reliable, flexible and accessible at all locations.

The revolutionary changes in the communication network in the twenty-first century have enabled the technology-based communication more swift and reliable. Commonly used modern communication infrastructure systems include local area network (LAN) and wide area network (WAN). LAN refers to a group of computers and associated devices (printers, scanners, etc.) that are connected to a server within a small geographic area such as an

Table II. Summary of data inventory module in examined studies

S. No.	Author	Baseline data	Historical records of disasters	Resource registry	TDPs registry	Missing persons registry	Database type
1.	Corporación (1994)	Yes	Yes	Yes	No	No	Online database
2.	PAHO (1998)	No	No	Yes[a]	No	No	NA
3.	Kitamoto (2000)	No	Yes	No	No	No	PostgreSQL
4.	Lakovou and Douligeris (2001)	Yes	No	Yes	No	No	Oracle
5.	Meissner *et al.* (2002)	No	No	Yes	No	Yes	NA
6.	Eraslan *et al.* (2004)	Yes	Yes	Yes	No	No	NA
7.	Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan (2004), Turoff, Chumer Walle and Yao (2004)	No	No	Yes	No	No	NA
8.	International (2005)	Yes	No	Yes	No	No	NA
9.	Murphy and Jennex (2006)	No	No	Yes[b]	No	Yes	Online database
10.	Ariyabandu (2009)	No	No	Yes	Yes	Yes	Linux-Apache-MySQL-PHP/ Postgres (LAMP)
11.	Tata (2009)	Yes	Yes	Yes	No	No	NA
12.	Atteih *et al.* (2010)	Yes	No	Yes	No	No	Oracle
13.	Ganeshkumar and Ramesh (2010)	Yes	No	No	No	No	GIS Server
14.	Hassan *et al.* (2011)	No	No	Yes	No	No	NA
15.	Dorasamy *et al.* (2012)	No	Yes	Yes	No	No	NA
16.	Lee *et al.* (2012)	No	No	Yes	No	No	NA
17.	Saeed *et al.* (2013)	Yes	No	Yes[c]	No	No	GIS Server
18.	Li *et al.* (2014)	No	No	Yes	No	No	P2P-based network database
19.	EmerGeo (2016)	Yes	Yes	Yes	No	No	NA

Notes: n/a, not available. [a]Includes data of material and equipment resources only; [b]includes data of shelter only; [c]includes data of human resources only

office building. Ethernet and Wi-Fi and are the most commonly used LAN technologies. WAN consists of two or more LANs and allows a computer network to span over a relatively large geographical area. Public networks, such as the telephone system, are used to connect computers to WAN. WAN could be operational through Ethernet, Wi-Fi and general packet radio service (GPRS). The access to the remote computer is done through an internet browser. internet cable network or public network becomes vulnerable to the damages during a disaster. As a result, wireless LAN, wireless WAN and satellite communications are considered to be reliable communication infrastructures in these situations. In addition to these, wireless personal area network (WPAN) can also be used to connect devices in an individual's limited workspace such as Bluetooth.

A schematic of the overall communication demand during a disaster is illustrated in Figure 4. It is seen in Figure 4 that a site response centre is established by the first responders after reaching the disaster site to send updates to the central command unit. This unit, in turn, provides these updates to the local government offices responsible for dealing with the disaster. The information is analysed by the public decision makers and resource allocations are carried out using the administrative control module of DMIS (Figure 1). Thereafter, the relief agencies are mobilised by the government to deliver the supplies to the affectees. The data and information at local government offices are also stored as backup in remote data servers for protection.

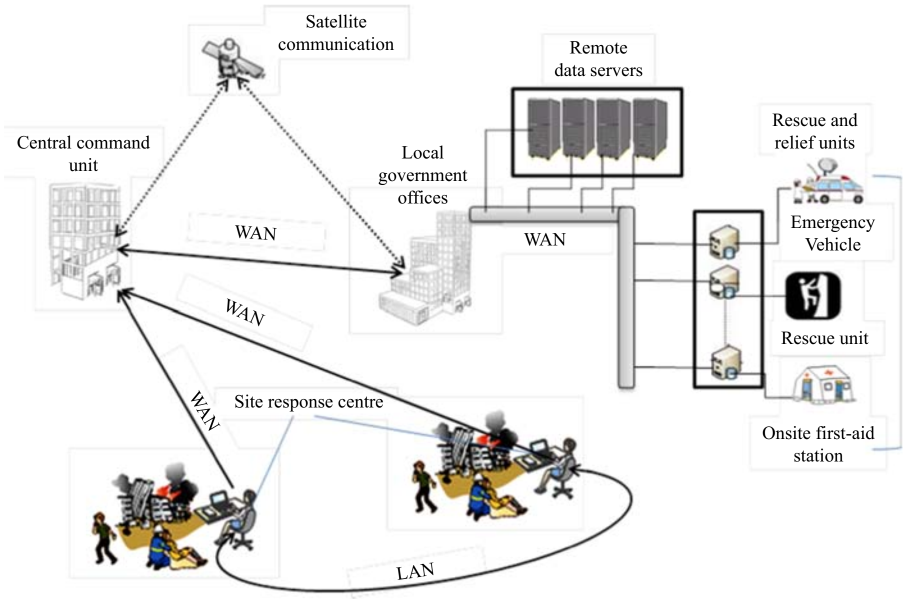

Figure 4. Communication demand during a disaster

The communication infrastructure proposed by the researchers for DMISs in the examined studies is summarised in Table III. The details of infrastructure design for internal communication within an organisation and externally between different organisations are given in Table III. A difference in the proposed communication infrastructure with the development of technology is noted in Table III and the increased use of wireless LAN and WAN is evident in the studies presented over the last one decade. Similarly, use of GPRS is also introduced to facilitate external communication in the absence of IT infrastructure network. It is noted in Table III that most of the studies have suggested WAN to connect site response centre with both the central unit and the local government. On the other hand, LAN has been proposed to be a communication channel within organisations. Few studies have also considered satellite communications which improve the reliability and survivability of services during a disaster. An exception from the remaining studies is that of Li *et al.* (2014) where a peer-to-peer (P2P) architecture has been proposed to manage distributed data sets of the affected community. A P2P network is created when two or more computers are connected and share their resources without going through a separate server.

The studies carried out by Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan (2004), Turoff, Chumer Walle and Yao (2004), Hassan *et al.* (2011), Dorasamy *et al.* (2012) and Murphy and Jennex (2006) did not provide specific details regarding the communication infrastructure although these authors have mentioned use of devices for communication such as personal computers, servers, laptops, PDAs and smart phones. Communication infrastructure is not required in DISs, as mentioned earlier.

Management of resources

A link is provided between the data inventory and communication infrastructure during the management of resources. An overview of resource management cycle is illustrated in Figure 5. It is seen in Figure 5 that resource management cycle starts at field operators who provide disaster situational updates to the site response centre established at the disaster sites. This communication could be through either voice communication (using wireless or

S. No.	Author	Internal communication	External communication
1.	Corporación (1994)	n/a	n/a
2.	PAHO (1998)	Radio	Satellite communications
3.	Kitamoto (2000)	n/a	n/a
4.	Lakovou and Douligeris (2001)	World wide web	World wide web
5.	Meissner *et al.* (2002)	Wireless LAN	Wireless WAN, Satellite communication
6.	Eraslan *et al.* (2004)	Wireless LAN, Wireless PAN	Radio, GPRS, Wireless WAN, Satellite communication
7.	Turoff, Chumer, Hiltz, Klashner, Alles, Vasarhelyi, Kogan (2004), Turoff, Chumer Walle and Yao (2004)	–	–
8.	International (2005)	Wireless LAN	Wireless WAN, Satellite communication
9.	Murphy and Jennex (2006)	–	–
10.	Ariyabandu (2009)	LAN	WAN
11.	Tata (2009)	n/a	n/a
12.	Atteih *et al.* (2010)	LAN	GPRS
13.	Ganeshkumar and Ramesh (2010)	n/a	n/a
14.	Hassan *et al.* (2011)	–	–
15.	Dorasamy *et al.* (2012)	–	–
16.	Lee *et al.* (2012)	Wireless LAN	Satellite communication
17.	Saeed *et al.* (2013)	n/a	n/a
18.	Li *et al.* (2014)	Peer-to-Peer (P2P)	Peer-to-Peer (P2P)
19.	EmerGeo (2016)	Wireless LAN	Wireless WAN, Satellite communication

Note: n/a, not applicable

Table III. Summary of communication infrastructure design in examined studies

satellite phones) or e-mails. These data are entered into DMIS and are sent to the central command unit through the employed communication infrastructure (Table III). The data are analysed at the central command unit and reports are generated which are sent to local government offices or DM authorities in the form of demand for aid supplies. The local government offices maintain the record of available resources. The demands received from the central command unit are compared with those available and decisions for the transactions of resources are made by the public decision makers. Damage statistics and situational updates are also prepared by the local government/DM authority offices. Note that the details of resources suggested by different studies are given in Table II.

System development

The available information related to the development of DMIS is limited in the literature. Eraslan *et al.* (2004) used unified process (Arlow and Neustadt, 2008) which is an iterative and incremental software development process framework. Unified modelling language (UML) was used to describe the system structure and behaviour. The interaction between different actors in the system was specified with use cases (Cockburn, 2008) which are part of UML diagram. Sahana (Ariyabandu, 2009) is open source software developed using Linux-Apache-MySQL-PHP/Postgres (Teter, 2006) web development platform; the code of the programme was written in PHP scripting language. Ganeshkumar and Ramesh (2010) used ArcGIS (ESRI, 2011), MapObjects (ESRI, 2011) and the programming language platform VB.NET (Vick, 2004) to develop the application for finding the shortest route to a relief centre. EmerGeo Fusionpoint (EmerGeo, 2016) employs different software libraries

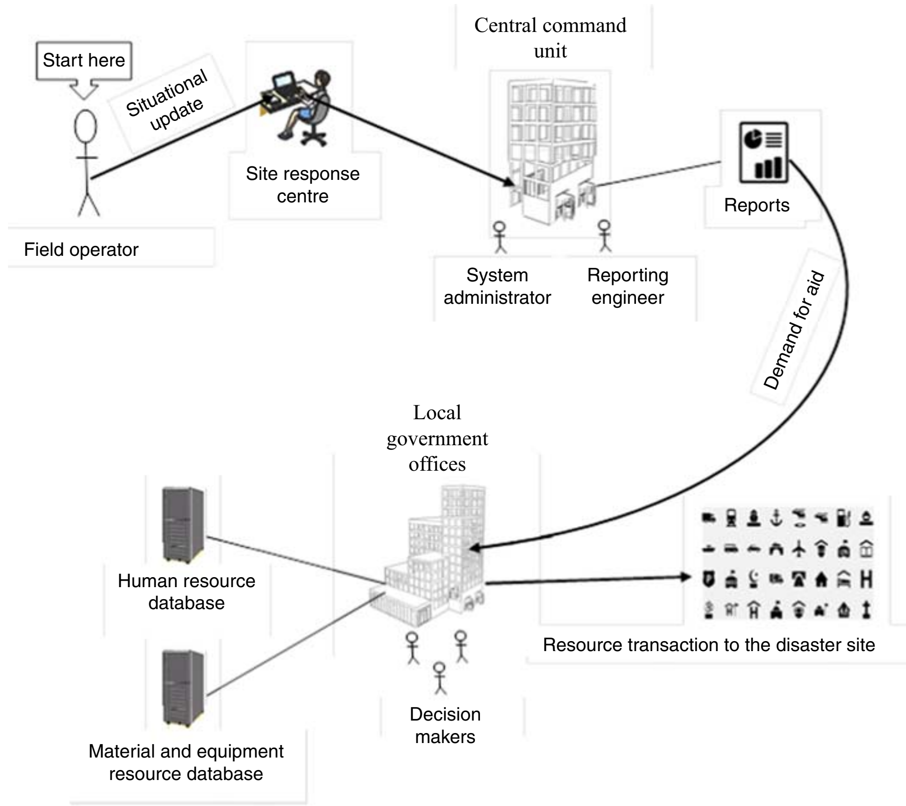

Figure 5. Scheme for flow of information to manage disasters

such as ETeam (NC4, 2016), WebEOC (Intermedix, 2016), Intergraph (Intergraph, 1976), Versaterm, Google Maps, Microsoft Bing and Open Street Map to provide functionality and services. Generic mapping tools (Wessel and Smith, 1998), advanced visualisation systems (AVS) (Upson *et al.*, 1989), Java (Arnold *et al.*, 2006), oyster, oracle (Oracle, 2016) and hypertext markup language interface supported through a set of UNIX (Raymond, 2004) script have been employed in the development of IMASH (Lakovou and Douligeris, 2001).

Future opportunities

The review of the studies presented in the aforementioned sections indicates a number of future opportunities which can increase the effectiveness of DMISs in managing response to a disaster. Firstly, baseline data (demographic distributions, building typology, transportation network, critical facilities and supply lines) is important information for the post-disaster relief operations. Therefore, geographically referenced baseline data should be collected and stored in a separate remote server. The information specific to a disaster event can be pushed to DMIS from this server through a communication mechanism. These data can be beneficial for the response agencies for effective response to a disaster in a particular area. As a result, availability of geographically referenced baseline data could improve the response in combination with DMIS. The provision of these data can be beneficial for the response agencies to make an effective action plan to respond to a disaster in a particular area.

Effective DRR reduces the need of response to the needs of affectees to a large extent. As a result, more attention is paid to mitigate the disaster risk. The addition of a module for hazard analysis would appear a logical step for a DMIS. The obtained results could be combined to provide integrated multi-hazard reports and maps which can be used by disaster managers to develop DRR strategies for the reduction of risk of damages.

Of all the studies examined in the presented paper, only EmerGeo (2016) includes a module of early warning. This module is used for alerting the agencies and communities of an emerging dangerous condition which provides an opportunity to take actions in advance to reduce the associated risks. In addition, sufficient warning time can help in making better preparations to deal with post-disaster situations. The longer the preparation time the greater the savings in human life, household assets, livestock and stored provisions. In view of these benefits, a module of early warning system should be provided in DMIS. Different agencies such as metrological department, flood authorities, ocean authorities and other agencies dealing with different natural hazards may be connected to the central command unit to provide regular situational updates. The central command unit can send situational warning messages to the local government officials, response agencies and media to alert the communities.

Accurate and instantaneous data over large areas can be obtained using satellites. Therefore, remote sensing could be a useful tool for DM as it can provide a clear picture of a disaster stricken region immediately. These data can also be used for risk modelling, early warning alerts and for identifying the escape routes.

Finally, the role of media is crucial during a disaster and can be included in an automated DMIS. This can help in sending early warning alerts, in keeping people updated about the situation and relief activities, and in sending appeals for aid supplies during a disaster.

These aforementioned suggestions have been made part of DMIS (Rafi and Lodi, 2015) that the authors have proposed to National Disaster Management Authority in Pakistan.

Concluding remarks

An effective response to a disaster requires swift flow of information and integrated response activities. The use of computing technology in DM can help in achieving these objectives. Automated DMISs have been suggested and developed in different parts of the world. A significant increase in the research in the field of DMIS is noted since about 2004. This paper reviews the studies related to the proposed and developed DMISs with a view to examine their similarities. In addition to DMIS, systems providing disaster inventory only (DIS) have also been proposed in the literature. These are the databases of past and on-going disasters without any response management functionality.

Database inventory and communication infrastructure are the two major components of a DMIS. Variations in the type of data proposed for different DMISs exist based on the functionality requirements. No particular trend appears from the reviewed studies for the design of databases as this is dependent on the functionality requirements of the system which were found to vary from one study to the other. Only few of the examined studies provide management of missing persons and TDPs. The trend for communication infrastructure design is towards satellite communication owing to its higher reliability and survivability after a disaster. The future opportunities identified, based on the review of the presented studies, include creating geographically referenced databases, use of remote sensing data, and modules for DRR, early warning system and media communication. Lastly, understanding of the areas of improvement in DMIS can increase by testing the systems in real situations.

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