Considering Emergency and Disaster Management Systems from a Software Architecture Perspective

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Abstract — **Emergency and disaster management has become a widely researched area in the last decade. The use of Information and Communication Technologies (ICTs) has been highly advocated for addressing the obstacles and improving decision-making in the event of a disaster. A number of ICT support systems and frameworks, both conceptual and application-based, have evolved over time to support the highly time and collaboration intensive task of emergency and disaster management. The use of ICTs like GIS has helped the relief worker to a great extent.**

This paper is based on a survey of the existing systems, ongoing research projects, supporting systems and concepts. These systems have been classified based on their use in the four stages of Comprehensive Emergency Management (CEM) as categorized by the Federal Emergency Management Agency (FEMA). Further, the systems are broadly divided into monitoring, live and simulation systems.

It is clear that each stage of the CEM, along with the purpose of the corresponding software system, will have specific quality attributes to effectively address the requirement. Based on the study of these diverse systems and concepts, we highlight certain vital qualitative concerns for emergency and disaster management software systems. We look at these concerns from a software architectural perspective and suggest some ways to address and incorporate them into future endeavors of research and deployment in this area.

I. Introduction

DISASTER is a broad term which can include a range of crisis situations arising as a result of natural and/or man-made phenomenon. Disasters have varying magnitudes, temporal and spatial dimensions and varying social and economic consequences. The impacts of disasters change the socio-economic environments of human life locally, and in many cases, regionally [1]. We understand disasters as "*a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources*" [1]**.** In the event of a disaster, the affected population needs large scale material and humanitarian assistance to cope with the loss, and thereafter, recover from it. The total systematic coordination of activities undertaken before and after a disaster, are termed as disaster management activities [1]. Disaster management, as a process, comprises of four distinct phases: Mitigation, Preparedness, Response, and Recovery.

With the increase in urbanization, disasters (both natural and man-made) have had a larger impact in terms of value lost as well as the loss of life [2]. Rapid advances in the development of information and communication technology (ICT) have resulted in their use in all domains of life and society. Disaster management is no exception. As a result, ICT for disaster management has become a widely researched area. Although, [3] contains a clear differentiation between emergency response and disaster response, for our study we do not make any distinction between the two. Rather, we concentrate upon the overall software systems' characteristics and concerns. A large number of software systems, tools and frameworks have been developed in the last decade. This has resulted in many, but partially useful solutions. It is important to note, however, that the quality and longevity of a software system is determined by its software architecture [4]. The quality attributes of a system (also known as the non-functional attributes) are the desired properties of a software system – beyond its delivered application functionality. Whether a system will be able to exhibit its desired (or required) quality attributes is substantially determined by its software and hardware architecture [5].

In this paper, we examine disaster management systems from a software architecture perspective. We identify the types of systems and the phases within which they are expected to operate. We outline the vital quality attributes required in the different types of software systems developed for disaster management. We examine some of the existing systems developed for responding to emergency and disaster situations. We describe the software architectural concerns addressed by the existing systems. We thus develop a framework within which emergency and disaster management systems can be analyzed.

Section II contains a description of the disaster management process, its phases and reflects on the use of ICTs for emergency and disaster management activities. In Section III, we categorize disaster management systems based on their operational phase and characteristics. Thereafter, in Section IV, we define various software quality attributes in the context of disaster management. We also outline which type of system needs to possess which qualities. In Section V, we present some existing disaster management systems that we studied. Section VI categorizes

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the existing disaster management systems and highlights the architectural concerns addressed by them. Section VII concludes the paper by making a note of the objective and future direction for disaster management systems research and development.

II. Disaster Management and the Use of ICTs for Disaster Management

In order to accurately categorize and analyze disaster management systems, it is important to have a clear understanding of the disaster management process and its distinct phases. Each phase has a different objective and different set of qualitative system requirements that will help in accomplishing those objectives.

The Federal Emergency Management Agency (FEMA) has categorized four stages in a Comprehensive Emergency Management system [6]. They are structured by time and function for all types of disasters. The phases [7] are:

A. Mitigation/Prevention

This phase focuses on long-term measures for reducing or eliminating risk [8]. It is necessary to prevent hazards from developing into disasters. It is vital to identify, analyze and document the possibility of an emergency event or a disaster and its potential consequences or impacts on life, property and environment [1]. The results of this phase are essential for the next preventive and response phases. It includes long-term activities designed to reduce the effects of unavoidable disasters. Mitigation measures can be structural or non-structural [9]. Structural measures use technological solutions like flood levees. Non-structural measures include legislation, land-use planning and insurance. It includes providing regulations regarding evacuation and communication of risks to the public.

B. Preparedness

In this phase governments, organizations, and individuals, develop plans to save lives and minimize disaster damage. Preparedness is a continuous cycle of planning, organizing, training, equipping, and exercising, evaluation, and improvement activities [10]. This is to ensure effective coordination and enhancement of capabilities to respond to and recover from the effects of disasters. Preparedness measures seek to enhance disaster response operations through positioning and provisioning of inventories for emergency use and training of ground and emergency operations center (EOC) personnel. A well-rehearsed emergency plan developed as part of the preparedness phase enables efficient coordination of response.

C. Response

The response phase starts when avoidance efforts fail and events trigger a crisis [7]. At this point, organizations shift their resources and efforts towards response activities designed to provide emergency assistance for victims. This involves mobilization of emergency services and first responders, initiation of emergency evacuation, situation assessment and requirements assessment procedures. They also aim to stabilize the situation and reduce the probability of secondary damage and speed-up recovery actions.

D. Recovery

Recovery activities aim to return the living conditions to normal or better and they usually include two sets of activities [1].

1) Short-term recovery activities return vital life-support systems to a minimum operating standard.

2) Long-term recovery activities may continue for a number of years after a disaster.

Recovery efforts are primarily concerned with actions that involve rebuilding destroyed property, re-employment, and the repair of other essential infrastructure. This phase also represents the first step to a new *planning/mitigation phase*, because this is the point when the analysis of the cause of the disaster or emergency takes place.

[11] has outlined and emphasized various aspects of disaster management where the use of ICTs will be beneficial. The many facets of disaster management have been discussed and suitable IT-based solutions have been recommended for improving disaster management. On the other hand, [7] has lucidly summarized both, supportive and critical views of several scholars regarding the increasing use of IT in Public Safety Networks (PSNs), over the last two decades. It is well known that IT has as-yet-unrealized potential to improve how communities, the nation, and the global community handle disasters [11]. It can contribute, in a big way, toward enhancing inter-agency coordination and collaboration in the highly time sensitive process of disaster management. But, some studies criticize the lack of reliability of the technologies deployed for disaster response. The reasons attributed to this are unavailability of IT infrastructures during disaster response, lack of technological flexibility, non-user-friendliness of IT interfaces, etc. [7]. This clearly points to the lack of good understanding of the important quality attributes for a disaster management system.

Our research aims to address this issue by making explicit the various non-functional attributes required of disaster management systems subject to the phases within which they operate.

III. Categorization of Disaster Management Systems

Disaster management systems can be categorized on the basis of their characteristics and the phase in which these are used. Our classification of disaster management systems is as follows:

A. Monitoring System

A monitoring system records data as real world events occur. These data are helpful in spreading timely warning to agencies and populations at risk. It allows them to take precautionary measures to prevent and reduce loss of life and property caused by events like earthquakes, floods, tsunami, forest-fires etc. The monitoring data may be used to run simulation systems which are described below.

B. *Live System*

A live system, as the name suggests, will be up and running during the response, relief, and recovery phases of a disaster. Such systems will assist the responders in issues such as situational awareness, information gathering, exchange and dissemination, and management of relief effort information.

C. *Simulation Systems*

Simulation systems are used to present computer-generated scenarios using real world situations. These are used in the preparedness phase to train the rescue, relief and decision-making personnel. Simulation systems are crucial as they can be used to present varied scenarios and check the efficacy of procedures to deal with them. More sophisticated simulation systems can be used to predict the disaster progression and damage estimation.

IV. Software Architecture Analysis Of Disaster Management Systems

In the previous section, we categorized disaster management systems. Certain architectural concerns are vital for the development of these systems. We now define from [5], [12] the meaning of each of the quality attributes and their implication in the context of disaster management.

A. *Availability*

Traditionally, availability is concerned with the long-term proportion of time the system is working and delivering its services. In the case of systems operating in the preparedness and response phase of disaster management, it is important that they work round the clock collecting real time data. For example, monitoring systems should be highly available irrespective of the climatic conditions prevalent in a geographical area.

B. *Reliability*

Reliability is concerned with the probability a system will not fail over some specified interval of time. This means that the system should not fail when it is needed the most. Often, systems are liable to failure when the demand is high i.e. during crisis situations. It is crucial that the communication channels for disaster warning are reliable, i.e. the system should be built taking into account the overload on these channels during critical incidents due to high public demand. Reliability is also necessary for information systems used in the response phase.

C. *Modifiability*

Modifiability is the ability of the system to be changed after it is implemented. It is usually concerned with the cost of change. For example, a simulation system should be customizable. It should be able to simulate different types of emergency and disaster situations, for thorough preparedness. It should be designed in such a way that it can be changed to incorporate new realities that may enhance its functionality.

D. *Maintainability*

In the context of disaster management software systems, maintainability refers to the ease or difficulty of maintaining a system in such a state that it will be ready for use in the sudden, critical situations arising on the occurrence of a disaster. This includes system and database maintenance costs. Maintainability [13] is important, especially for live systems, whose working is extremely critical in the post-disaster period.

E. *Interoperability*

Interoperability means that a number of organizations coming together to cope with a major disaster should be able to exchange data for effective disaster response. The concern here is to use a standard data interchange format. XML, for instance, is a flexible format because XML documents can contain all required information as well as meta-information to extract the semantics of the information. It can be used for simple messages as well as complex maps [14].

F. *Scalability*

Scalability is the ability of a computer application or product to continue to function well when it (or its context) is changed in size or volume in order to meet a user's need. In the disaster management context, for example, the UN News Centre reported that in 2008, the death toll due to natural disasters was 235,816 and it was more than three times the annual average of the previous eight years. A system built for relief and rescue has to be scalable to handle such high numbers with reasonably low latency to remain functional and useful in such critical conditions. Similarly, a system should be able to scale adequately by the type of disaster being serviced.

G. *Performance*

Performance is the ability of a system to allocate its computational resources for service in a manner that will satisfy timing requirements. Another term commonly used is 'latency'. System performance is one of the primarily observed qualities of a software system. Any disaster management system will have a number of competing requests and inability to service those requests within an expected amount of time will make the users abandon the system for other means. With the increasing richness of information, processing of data in a timely manner becomes very important. For example, applications like a missing persons' registry, a camp registry, etc. need to cater to a large number of requests that flood in after a disaster.

H. *Portability*

Software portability is the property of a software system to be executed on a variety of software and hardware platforms. In some instances, the software system should be portable enough to run on handheld devices carried by rescue and relief workers to the site of the disaster. Emergence of newer tools and platforms makes it imperative that long-lived systems – especially simulation-based decision support systems be easily ported to the new platforms. In this manner, these systems can take advantage of the technological improvements available. The ease with which this can be done affects other quality attributes and hence the value.

I. Usability

Usability is concerned with how easy it is for a user to accomplish a desired task and the kind of support the system provides. In the disaster management context, the rapid turnover of personnel attending to the efforts requires that the system be intuitive and not have a steep learning curve. It need not be sophisticated. The main concern for the system is being easily usable and informative. The term usable, here, includes user-friendliness, accessibility and easily interpretable information useful to the volunteers, victims and their families.

TABLE I
SOFTWARE ARCHITECTURAL CONCERNS OF DISASTER MANAGEMENT SYSTEMS

Type of System	**Desirable System Qualities**
Monitoring System	Availability Interoperability Reliability
Live System	Interoperability Maintainability Performance Portability Reliability Scalability Usability
Simulation System	Interoperability Modifiability

V. DISASTER MANAGEMENT SYSTEMS: AN ANALYTICAL STUDY

In this section, we review some existing disaster management software systems. We describe their basic functionality and provide a brief software architectural analysis of the same.

A. Envimon

Envimon is a project which was undertaken by the VTT Technical Research Centre of Finland in partnership with National Research Institute for Earth Science, Japan. The main objective of the project was to build systems to meet diverse environmental monitoring needs. Envimon was one of six Earth Observation (EO) applications built onto a common software framework EOFrame [15], which was also designed and implemented in the project.

Envimon is essentially disaster information and monitoring system that addresses the need for *"real time disaster management*". This is done with the help of Synthetic Aperture Radar (SAR) [16], [17] data. It works during early warning and post-disaster mitigation phases. It has been used in case of floods and landslides which are detected by topographic changes. The system essentially, processes the SAR data and, on detecting topographic changes, it alerts the public by cell broadcast messages, etc. The data are further refined by disaster analysts to produce the damaged area maps, etc. The system is fairly *user-friendly* and has an *extended reach* to the public as it has been implemented as a web application. It will also work as a web based information source for the general public. Thus, it provides geographically spread clients with views to a shared disaster database.

Envimon acts as an information channel between the involved authorities and experts for producing and sharing up-to-date information and prognosis for the disaster circumstances. It is *flexible* in the way that it can use Google Earth viewer as an optional channel for publishing satellite based disaster maps.

Envimon has *consistent availability* even after a disaster because of the use of SAR data. SAR data have a great potential as a source of relevant and near real time information because it can provide data irrespective of climatic conditions and sun illumination.

B. Spatial Data Infrastructure and Intergraph GeoMedia®

Most of the information required for disaster management has a spatial component [18]. This gives rise to several problems in the collection, processing and usage of disaster management data [19], [20]. These problems cause delays that adversely affect the quality of decision-making and consequently, the disaster response is also affected badly.

A pilot project conducted in Iran [21] showed that web-based GIS using an SDI framework facilitates and improves the decision-making process and inter-agency coordination. It reduces the response time by 60%. This project also developed an SDI conceptual model which outlined the components of SDI.

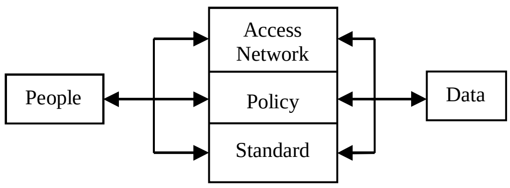

Fig. 1. Components of the developed SDI conceptual model for disaster response[2]

Intergraph's [22] emergency management solution supports emergency management activities for natural disasters and large public events. Their SDI application helps in collaboration and distribution of geospatially-related data. This is important because of the variety of required datasets for disaster response. No individual organization can collect and keep up-to-date all of its required spatial datasets before and particularly after occurrence of disasters [2]. Decision makers always need to be updated on the latest emergency situation. This application provides the technology framework needed for cost-effective and efficient communication of such data.

The Intergraph GeoMedia® product portfolio provides a *customizable* solution which acts as a foundation for an SDI technology extension. This technology extension is to fulfill the core requirements of *sustainability*, *interoperability*, and *flexibility*. These concerns are crucial for timeliness and inter-agency coordination during disaster response. GeoMedia® SDI Portal services provide the building blocks for empowering existing browser applications with SDI technology. It offers a set of connectors, which can enhance the functionality of all kinds of thin and smart clients.

C. Sahana

The Sahana Disaster Management System [23] development was initiated by considerable relief coordination needs in Sri Lanka following the Indian Ocean tsunami in 2004. It is designed to address the urgent need for the establishment of an institutional framework and a robust information communication system. It is web-based free and open source software specifically designed for disaster management. It helps in solving the problems in coordination of relief supplies, management of camps, inventories supplies, finding missing people and managing volunteers.

Sahana proved to be an effective IT based solution in the post-Tsunami relief and recovery phase. It has a *component-based design* where each component is designed to address a particular coordination problem in disaster response, and can be dynamically included in any installation. It has both lightweight and large-scale deployment options. The *portable* version of Sahana does not need to be installed, as it comes pre-set-up and requires only to copy and click for execution. Sahana is *scalable* because it can be scaled up or down from a single notebook computer (with or without a portable WLAN) to a fully distributed networked platform.

Sahana is developed using LAMP (Linux-Apache-MySQL-PHP/Postgres) under open source licenses. The database layer is accessed through the AdoDB abstraction layer; this provides *database independence* to Sahana. [21] contains some details on the Sahana architecture.

D. First Trak^{TM} by Disaster Management Solutions

DMS First Trak^{TM} Patient Tracking Solution (PTS) [24] uses provides real-time, electronic patient tracking solutions that track the number, status, and location. It is *fully scalable and configurable*. First Trak^{TM} PTS has been deployed in over 60 entities across the United States, to manage mass casualty incidents and forward movement of patients. Key features of First Trak^{TM} PTS are:

1)Reliability: In large scale catastrophes standard internet lines may be down for days or weeks. When this happens, tracking systems that depend entirely upon web based applications become non-functional. DMS uses internet access by satellite phone to send data to the central server.

2)Scalability: First Trak^{TM} can be configured for an individual entity that wants a local system, all the way up to an entire region that requires inter-agency functionality. Currently, First Trak^{TM} is utilized in operations that run over 20,000 transactions per day.

3)Customizable and Configurable: DMS offers long term flexibility with First Trak^{TM}'s Vertical Software Engine (VSE). This innovative solution allows DMS to quickly roll out updates and new functionalities to clients without the need for costly programming changes, and without loss of clients' custom configurations.

E. Decision Support Systems for Disaster Management

Decision Support Systems (DSS) are intended to complement the cognitive processes of humans in their decision making [6]. They can be used during disaster management for preparedness, through training support and actual response activities in the post-disaster phase. A number of prototypes and systems described in [6], have been developed for different scenarios like toxic spill management, earthquake mitigation policy analysis, nuclear power plant accidents, coast guard search, and rescue response. The best thing about DSS is that the components are *easily customizable* for various kinds of disasters. These systems are essentially menu-driven and thus, fairly easy to use.

F. Integrated Earthquake Disaster Simulation Systems

Integrated Earthquake Disaster Simulation Systems (IEDSS) [25] is a Japanese government project started in 2002. It was built for earthquake disaster simulation and mitigation management. The key objectives of this work were to make the system highly functional, inexpensive, and robust. This is possible with the use of Risk Adaptive Regional Management Information System (RARMIS) [25] and storing data in a common database constructed on the Spatial-Temporal GIS.

RARMIS links disaster management information system seamlessly with the daily operation information systems of municipal governments. These systems are *easily maintainable* because they use a common database and share the computer resources in the municipal government. Also, the system uses multi-agent simulators for emergency and recovery actions. Damage and disaster progression simulators predict the efficacy of the emergency professional activities, such as fire brigades, ambulances etc., faster than the real time progress. The use of these technologies has increased the versatility of the system for use across the preparedness, response and recovery phases.

VI. PHASE-WISE CATEGORIZATION OF EXISTING DISASTER MANAGEMENT SYSTEMS

TABLE II
CATEGORIZATION OF DISASTER MANAGEMENT SYSTEMS

	Mitigation	**Preparedness**	**Response**	**Recovery**
Monitoring System		Envimon Intergraph GeoMedia®	Intergraph GeoMedia®	
Live System			Sahana First Trak^{TM} PTS	Sahana
Simulation System	Customized Arc-GIS[26]	DSS IEDSS	DSS IEDSS	IEDSS

PTS: Patient Tracking Solution
IEDSS: Integrated Earthquake Disaster Simulation Systems
DSS: Decision Support System

TABLE III
SOFTWARE QUALITIES IN SOME EXISTING DISASTER MANAGEMENT SYSTEMS

Disaster Management System	Software System Qualities
Envimon	Availability Interoperability
Intergraph GeoMedia®	Interoperability Modifiability
Sahana	Modifiability Portability Scalability Usability
First Trak™ Patient Tracking Solution	Modifiability Reliability Scalability
Decision Support Systems	Modifiability
Integrated Earthquake Disaster Simulation Systems	Maintainability

VII. CONCLUSION

This paper outlines the software quality concerns that necessarily need to be incorporated in disaster management systems research and development work. This is vital for the development of sustainable systems that will effectively achieve the objectives of the disaster management phase in which these are to be used. The analysis provided here is based on the study of some existing systems in this area. We have looked at these systems from a software architectural perspective. This analysis will provide certain benchmark quality attributes and perspectives for software systems being developed for disaster management.

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