Trinity College Dublin

School of Computer Science and Statistics

MSc in Health Informatics

Supervisor: Lucy Hederman

SPATIAL DATA INFRASTRUCTURE

IMPROVING FIT-FOR-PURPOSE OBJECTIVES FOR SPATIAL DATA MANAGEMENT IN EMERGENCY AND DISASTER PLANNING

James Sweeney, BA MRUP MSc

Jaysweeney88@gmail.com

Dissertation submitted to Trinity College Dublin in partial fulfillment of the requirements for the degree of Master of Science in Health Informatics

2015

DECLARATION

I James Sweeney confirm that the work presented in this report is my own. Where information has been derived from other sources I confirm that this has been indicated in the report.

Signature: ______________________

James Sweeney

July 2015

PERMISSION TO LEND AND/OR COPY

I agree that the Trinity College Library may lend or copy this dissertation upon request.

Signature: ______________________

James Sweeney

June 2015

ACKNOWLEDGMENTS

I wish to express my sincere thanks to Dr. Lucy Hederman, Assistant Professor at Trinity College Dublin, for providing me with all the necessary guidance and facilities for this research.

ABSTRACT

Spatial Data Infrastructure: Improving fit-for-purpose objectives for spatial data management in emergency and disaster planning. - James Sweeney, BA MRUP MSc

Disasters happen. They can be man-made, biological or environmental, ranging from a mass flooding event, or an earthquake, to a terrorist attack. When they occur, there are national, community and non-profit organisations established to handle the response effort, and provide relief to affected communities. A vital tool in the arsenal of these organisations in coordinating this effort is data (whether it's real-time or historic). Having access to the right data enables responding organisations to see past trends, establish common operational pictures in times of disaster, and to develop predicative models to plan for the future. In emergency management, the context of this data is a crucial characteristic, specifically where is the incident, what is the existing situation prior to disaster (population, infrastructure etc…), and what are the resources available for a response effort (Hospital beds. Ambulances etc…). In this regard the spatial component of the data becomes the chief characteristic of the data itself.

Presently, much debate occurs around the content of data, and how it should/can be used. Little academic research is afforded to the practicalities of creating a place/infrastructure to store and effectively disseminate this data for emergency management. This dissertation will provide an assessment of the unique characteristics influencing a disaster situation that would conflict with traditional storage methods, and propose technical solutions to bridge this knowledge gap. The argument presented in the study is that while development should be guided by the principles of health provision and emergency management, the development process of an implemented system must be cross-disciplinary and tailored.

Keywords

Spatial Data Infrastructures, Data Frameworks, Crisis Management, Decision Support Systems, Interoperability, Data Standardisation.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

DEFINITIONS, ACRONYMS AND ABBREVIATIONS

Term	Definition
Application Programming Interface (API)	Specifies how software components should interact with each other. In practice, most often an API is a document that includes specifications for routines, data structures, object classes, and variables.
Base Map	Spatial data sets that provide the background upon which more specific thematic data is overlaid and analysed.
Cache	Is a place to store something temporarily, when looking at a web-page the requested files are automatically saved on your hard disk in a cache so when you return to the page the browser will get the files from your hard disk rather than the original server.
Cloud	Commonly refers to network-based services which appear to be provided by real server hardware, which in fact are served up by virtual hardware. Such virtual servers do not physically exist and can therefore be moved around and scaled up (or down) on the fly without affecting the end user - arguably, rather like a cloud.
Coverage	A data model for storing geographic features, a coverage stores a set of thematically associated data considered to be a unit. Features are stored as both primary features (points, arcs, polygons) and secondary features (ticks, links, annotation).
Data Harmonisation	The iterative process of capturing, defining, analysing and reconciling government information requirements, and data standardization as the mapping of this simplified data to international standards.
Decision Support Systems (DSS)	A decision support system (DSS) is a computer program application that analyses information or data and presents it so that users can make business decisions more easily and effectively.
Disparate Data	Is data from any number of sources, largely unknown and unlimited and in many different formats. Disparate Data are heterogeneous data. They are neither similar nor can be easily integrated with an organisations database management system.
Framework (Software)	Information architecture, a reusable software template, or skeleton, from which key enabling and supporting services can be selected, configured and integrated with application code. A Framework is a reusable software platform to develop applications, products and solutions.
Geographic Information System (GIS)	The entirety of a system used for processing location information including data, hardware, software, people and managed services.
Geo server	is an open source software server written in Java that allows users to share and edit geospatial data using OpenGIS standards Web Feature Service (WFS), Web Coverage Service (WCS) and Web Map Service (WMS). Geo server can also publish data from any major spatial data source using open standards.
Geospatial Data	Digital data that represent the geographical location and characteristics of natural or man-made features, phenomena and boundaries of the Earth. Geospatial data represent abstractions of real-world entities, such as roads, buildings, vehicles, lakes, forests and countries. Geospatial data refers to such data in any format, including raster, vector, point, text, video, database records, etc.

Infrastructure for Spatial Information in the European Community (INSPIRE)	Directive 2007/2/EC of the European Parliament. This seeks to ensure that the spatial data infrastructures of the member states are compatible and INSPIRE enables the sharing of environmental spatial information among public sector organisations and better facilitate public access to spatial information across Europe.
Map	A two-dimensional visual portrayal of geospatial data. A map is not the data Itself.
Metadata	Refers to data about data and is used in two fundamentally different concepts · Structured Metadata – design and specification of data structures · Descriptive Metadata –describes a resource for purposes
Open Geospatial Consortium (**OGC)–**	An international industry consortium of 475 companies, government agencies and universities participating in a consensus process to publicly available interface standards. The standards enable developers to make complex spatial information and services available and useful to all kinds of applications.
Open Source	Computer software with its source code made available where the developer provides users the right to study, change and distribute the software at no cost to anyone for any purpose.
PostGIS	Provides spatial objects / Features for the PostgreSQL database, allowing storage and querying of geographic information.
Spatial Data Infrastructure (SDI)	An SDI can be defined as a framework for coordinating the collection, use and implementation of spatial information. They act as a central repository of spatial information. They are created to house and manage spatial data and offer a user-friendly frontend enabling better interaction with the data stored within it.
Structured Query Language (SQL)	Is a standard interactive and programming language for getting information from and updating a database.
Web Map Service (WMS)	OpenGIS standard protocol for serving geo-referenced map tiles over the internet. Provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases. A WMS request defines the geographic layers and area of interest to be processed. The response to the request will be one or more geo-registered map images, returned as a JPEG or PNG that can be displayed in a web browser application. The interface also supports the ability to style the returned images using the Styled Layer Description standard.
Web Services	Are self-contained, self-describing, modular applications that can be published, located, and invoked across the Web. Web services perform functions that can be anything from simple requests to complicated business processes. Once a Web service is deployed, other applications (and other Web services) can discover and invoke the deployed service.

*The author does not claim ownership of any definitions in the above table. Definitions were extracted (in some cases verbatim) from literature related to each subject.

1.0 INTRODUCTION

1.1 STATEMENT OF THE PROBLEM / RESEARCH SUBJECT

Disasters and large scale emergency incidents present a number of distinct information management challenges. Specifically, data needs differ across stakeholder groupings depending on roles and responsibilities; data needs change across the disaster cycle; equally the dynamic nature of the environment is not conducive to data sharing. To date, the emphasis has been placed on the barriers and obstacles to data retrieval, data type and data quality. By contrast, limited emphasis has been afforded to the Spatial Data Infrastructures (SDI) and the systems in place to effectively integrate, disseminate and manage this information and disaster situation. Moreover, a greater emphasis needs to be placed on the actual environmental and technical characteristics of stakeholders involved to maximise information sharing and to more effectively harness the capacity of future SDIs in this area.

The key objective of the dissertation is to help bridge this gap by providing mechanisms that would enhance the decision informing process in the disaster management cycle. It will do so by analysing end-user requirements based on International, European and National projects, develop benchmarks for measuring the efficiencies of data management, and to test a prototype to inform effective decision making. Likewise, it seeks to lessen the time spent by responders on collecting, harmonising, analysing and visualising information that is coming from many disparate sources, in a variety of spatial formats. This time could and should be spent on ensuring that the response employed will meet the needs of the affected community and ensure that the reconstruction and recovery process will be sustainable and mindful of potential risks that may arise in the future.

This dissertation presents a standardised SDI for pan European usage tested against a number of disaster scenarios. Once tested, an SDI proposal will be presented. The development of such an SDI in parallel with state-of-the-art literature will uncover strengths and weaknesses in this framework of existing systems and act as a basis for a criteria-based evaluation on fit for purpose objectives. Finally, conclusions can be drawn on improving SDIs for future use in emergency and disaster planning.

1.2 RESEARCH HYPOTHESIS

Spatial data management for emergency planning is a key pillar in evidence-based responses to a disaster situation past, present and future. Thus, the dissertation will attempt to assess:

How can improvements in architecture be made to SDIs in order to tailor them for large scale emergency planning?

1.3 RESEARCH AIMS AND OBJECTIVES

In order to competently address this hypothesis a certain number of research questions needed to be answered and offered as a background to the empirical research. These questions relate simply to the previous attempts at developing SDIs for emergency management, the techniques used, as well as considering what to model, by examining the important issues affecting the case study area. Accordingly, in order to test this hypothesis the review of academic literature aims:

- **Objective 1:** To identify State-of-the-Art (SOTA) in academic literature in the areas of GIS, SDIs and Emergency Management. Moreover, because of the nature and application of these systems, a review of the current commercialised State-of-the-Art Incident Management Tools and disaster-specific Decision Support Systems (DSS) operating internationally.

Following a review of literature on the subject, an array of end user requirements will be derived and a basic application development created to demonstrate the challenges and successes in practice. To test the hypothesis, the main focus of the empirical study will be:

- **Objective 2:** To establish a set of criteria relevant to both the GIS discipline and that of emergency management (response, and recovery) with respect to usability, effectiveness to complete tasks, and technological constraints.
- **Objective 3:** To develop a prototype web-based SDI guided by these criteria requirements created from the end user needs.

- **Objective 4:** Test an operational web-based SDI via a scenario based assessment[1] in order to isolate potential advantages and limitations of existing systems;

Finally, the study will derive conclusions and a method whereby SDIs can be improved to provide a better structure upon which the situation and needs models are analysed.

1.4 METHODOLOGY

Secondary research of books; journals; internet sources; was carried out to gain a broad understanding of the topic as a whole. Subsequently, to ensure a suitable awareness of 'state of the art' perspectives, commercial product reviews as well as European and international research proposals and deliverable documents were assessed on scope, stakeholder requirements and results. The literature review aimed to inform both the social/procedural side of emergency management as well as the technical requirements.

The primary research will aim to develop a prototype SDI. Using recognised European/International standards and characteristics, criteria will be developed to assess efficiency of the contemporary SDI in the context of emergency management. The prototype will then be evaluated against these criteria to test the practicalities and efficiency of this type of system. Efficiency is the key description in this context meaning the ability to accomplish something with the least waste of time and effort. The argument being that all of these SDIs do the job they are meant to, but they could do it a lot better. The system will be a web-based front facing website utilizing GeoNetwork and GeoServer open source application framework.

[1] Chemical, Biological and Environmental Disaster Scenarios.

1.5 THESIS STRUCTURE

Chapter 1 – details the introduction, hypothesis, associated aims and objectives, methodology and structure of this thesis.

Chapter 2 – examines the academic literature on the concepts of GIS, Decision Support Tools, Spatial Data Infrastructures, and Emergency Management. The section also discusses the approaches to suitably measuring the requirements and effectiveness of SDIs for incident based decision support. The section recounts the benefits and limitations of this approach, and the advantages from tangent disciplines that utilise similar information frameworks.

Chapter 3 – presents the study design for the secondary and primary research conducted in the dissertation. The section outlines in greater detail the technical methodology and approaches used by the author to demonstrate his empirical study.

Chapter 4 – examines and validates the chosen methodology summarizing the empirical work carried out and the findings made. The section will test the aforementioned hypothesis of the thesis alongside aims and objectives of the dissertation.

Chapter 5 – draws some final conclusions and recommendations and highlights areas for further research or investigation.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The literature review has been divided into three sections. These sections reflect the background to spatial data infrastructures, GIS, and emergency management. In the first instance there is a discussion on emergency management and disaster response, how it is defined in the literature and what efforts have been made to classify and structure responses. The second section details the framework for this study, looking at SDIs, how they have developed, and their particular application in the field of emergency management. Finally, a review of European and international best practice with respect to the implementation of these tools.

2.2 INTRODUCTION TO THE EMERGENCY MANAGEMENT AND DISASTER RESPONSE

Disaster management continues to attract significant attention by the research community, particularly the field of data management and analysis. There remains a dearth of information and understanding of disaster management and data application through effective and systematic data channels (Hristidis *et al*., 2010). Disasters can be classified as Natural (earthquakes; hurricanes; floods; fires etc) which can be further compartmentalised into ‘rapid-onset’ natural hazards (such as cyclones) or slower ‘creeping crises’ (like drought, famine or disease), or Technological (nuclear power plant emergencies; hazardous materials; terrorism etc) all of which require rapid collation, comprehension, assimilation and processing of data flows in order to obtain a holistic and reliable dataset which captures the accurate nature, extent and authentic consequences of a disaster event.

As disaster response(s), or indeed mitigation encompasses significant emergency response capacity, resilience processes, and recovery and reconstruction efforts. Data assembly is critical to potentially avoid or curtail future problems. In this regard, specific data is essential for the timely management of almost all disasters in terms of prevention, advance warning, early detection, analysis and assessment, public notification, response mobilisation, damage containment and relief and medical care (Hristidis *et al*., 2010). An understanding of this is fundamental in order to implement an effective and efficient recovery and reconstruction plan. The capacity to effectively acquire, collate and share data is essential, and is the primary enabler for coordination between stakeholders to provide robust action plans and situation reports. Disaster management is a data-intensive activity which requires evaluation through numerous and eclectic forms/formats of data, and ultimately the consideration of instantaneous data combinations which have not been combined previously – or at least not within the confines of a systematic and coherent data framework (Fischhoff, B., 2005). Pertinently, this cannot be an isolated application as data streams require data integration and simultaneously external information feeds to furnish an accurate account and a *real* time picture/representation of what is required.

The increased frequency and intensity of disasters over the course of the last decade has heightened political awareness of the necessity for disaster preparedness strategies as well as highlighting the benefits derived from bolstering resilience within areas deemed vulnerable to incidents of disaster. Figures compiled by the Centre for Research on the Epidemiology of Disasters (CRED)[2] confirm that 357 natural disaster events occurred globally in 2012. Pertinently the 2012 figure was 9.3% below the annual average disaster occurrence for the 10yr period 2002-2011 (Guhu-Sapir, D., *et al*. 2013). In terms of disaster trends CRED cautions on the need to contextualise the disaster data and to remain objective when making inference on the increased frequency and intensity of disasters given the complex of climate and weather related disasters. Nonetheless interpretation of the statistics would infer a marked increase in both the number and associated impacts of natural disasters over the course of the 10yr period to the end of 2012 relative to the period 1992-2001 for example (Figure 1).

[2] CRED has been active for more than 35 years in the fields of international disaster and conflict health studies, with research and training activities linking relief, rehabilitation and development. In 1980, CRED became a World Health Organization (WHO) collaborating centre as part of WHO's Global Program for Emergency Preparedness and Response.

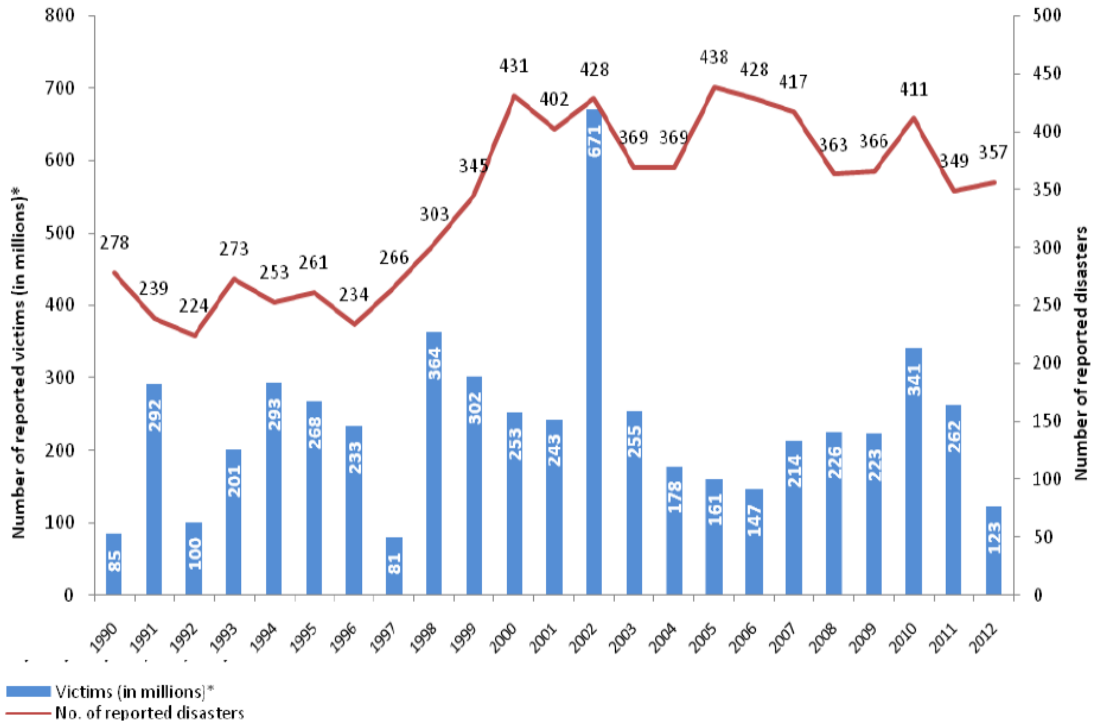

Figure 1 Natural Disasters in recent history (Source: Guhu-Sapir, D., et al. 2013)

The escalation in reported disasters post-1995 can in part be attributed to better reporting structures as well as more active data collection efforts on the part of institutions such as CRED. However, it is judged that in spite of concerted efforts to improve data availability and accessibility on disaster related events, a lack of robust and credible evidence based practice continues to inhibit the efficiency and coordination of recovery and reconstruction processes (Hosack, B., *et al* 2013). Existing data repositories have limitations in terms of their capacity to deal with the harmonisation of different forms of data (structured and unstructured) as well as the integration of new sources and formats of data as a consequence of technological advancement. Concerns persist around the regularity of data updates as well as the comprehensiveness of data capture which in the absence of key data variables affords only partially informed decision making. Murray (2011) highlights practitioner concerns in respect of the relative absence of robust and credible baseline data in many areas affected by disaster including the lack of data standardisation which has culminated in data inconsistencies and incomparable baseline information. Depending on the disaster context, data can be ad hoc, fragmented and too superficial for real time decision making and action. These limitations create significant problems in developing best evidence based practice guidance for disaster and crisis management.

Advances in the quality of data provision, more robust analytical processes as well as increased multi-disciplinary focus have all served to enhance the proficiency of the recovery and reconstruction process over the course of the last decade (Burkle, A and Greenough, G. 2008)(Bayntun, C., *et al*. 2012). However, in spite of such evolution, key stakeholders have been forthright in their views that more can and needs to be done to enhance the timeliness, credibility and interoperability of data (Neville, K. 2012)(Haghighi, D *et al*. 2012)(Hristidis *et al*., 2010). Moreover, there is a need to transcend the 'silo' mentality (Mays et al, 2013) which so often characterises major recovery and reconstruction efforts as well as a pertinent need to more effectively harness the as yet largely 'untapped' data resources that are affected communities within the disaster locale. It is widely recognised that affected communities are more responsive and collaborative to recovery and reconstruction plans if their insights and ideologies are encompassed within the recovery and reconstruction master-plan. Evaluations of disaster incidents over the course of the last decade have highlighted the need to more effectively mobilise and embrace the competencies and skills sets that exist within communities deemed vulnerable to recurring disaster incidents as a means of bolstering resilience.

2.2.1 Phases of disaster management

Government policy, as well as academic literature on the different phases of a disaster is present as far back as the 1930s. Practitioners and scholars within the field of emergency response have used these phases relating to the various stages of disaster to better comprehend their field of study, recognise issues, as well as improve their response to disasters (Coetzee, 2009). Typically, there are four main stages of a disaster that can be discerned: the Preparedness Stage, the Response stage, the Recovery stage and the Mitigation stage (Figure 2).These four stages are usually considered to be part of a cyclic process – a disaster management process where experiences and lessons learnt from a disaster give way to new risk reduction measures. This cycle is usually referred to as the *disaster management cycle*.

Figure 2 Disaster Management Cycle (Source: Adapted from Araz, M. and Jehn, M, 2013)

Each disaster stage has a different focal point and, consequently, has different data needs depending on the primary objective of the relief or preparatory efforts. Araz, M. and Jehn, M. note a number of important implications to the disaster management cycle (2013). First of all, the recovery process after a disaster event essentially constitutes a transition from relief to development. In the early stages, the emphasis is on providing relief and providing safety and security to those affected. In later stages the primary objectives shifts towards redevelopment, where the emphasis lies on restoring livelihood. Data and information needs will follow suit, and go from information about the vital aspects of the disaster and the affected communities in the early stage of disaster response to livelihood and community needs in latter stages.

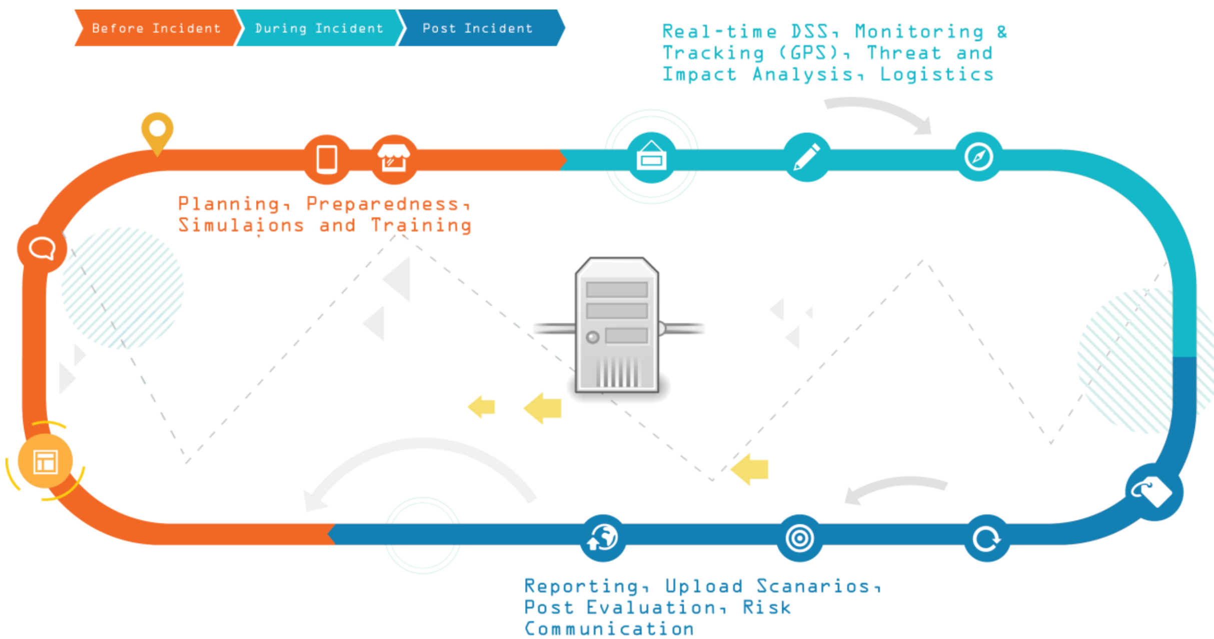

Figure 3 Differing needs based on disaster stage (Source: Adapted from Coetzee, 2009)

Secondly, and in relation to the first point made, there is a shift in ownership of the process. In the early stages of a major disaster, the response and recovery process will typically be in the hands of national authorities and capable humanitarian organisations. In later phases, when the situation has been stabilised, the primary control will be brought back to regional and local authorities and locally active support organisations (Aboueljinane, L., *et al.* 2013). Consequently, data and information needs will be more fine-grained and community-generated in latter stages than in early stages.

2.3 SPATIAL DATA INFRASTRUCTURES AND SPATIAL DATA

Formulating response efforts based on data depends on the resources available. These resources vary country to country, and organisation to organisation but the unique identifier that all of these resources have, is location. In this regard, the spatial component of data becomes quite significant in an emergency situation. The management of spatial data is carried out using Geographical information Systems (GIS) and Spatial Data Infrastructures (SDI). This section briefly outlines what these systems are and how they operate.

2.3.1 What is GIS?

Geographical Information Science (or Geographical information Systems) is a discipline used to enable users to investigate and visualise spatial information. The spectrum of this 'information' varies greatly in its size and complexity, but centres around understanding an issue purposely from its spatial context. It is used to produce outputs useful in decision-making processes allowing the user to view, interact, and interpret data in ways that reveal relationships, and patterns in data (Camara, G et al 2008).

Essentially, a GIS facilitates greater understanding of spatial phenomenon by bringing together Data, Capital (computers), People (ideas), Tools (spatial analysis softwares) to generate custom scenarios for real world issues. Accordingly, since the late 1960's the practice of using GISs to highlight the relationship between the studied phenomenon and its spatial component has provided huge potential as a tool for measuring a wide range of phenomena (van den Belt, 2004; Huser et al., 2009).

From a technical perspective, GISs act as a key tool to perform resource intensive (processor or human) or repetitive tasks, which automates as much of the complexity associated with data, statistics and modelling as possible. It enables a user to analyse data via fixed geo-processes or by developing custom ones. Data processed via a GIS system can then be developed into static mapping, reports or interactive outputs to engage a target audience.

2.3.2 Introduction Spatial Data Infrastructures

The term Spatial Data Infrastructure (SDI) refers to technologies, policies and people supporting the sharing of geographic information throughout all levels of government, commercial and the non-profit sectors, academia and citizens. The goal of an SDI is to make geospatial information more accessible to the public, to improve quality of this information, to avoid duplication effort and to "establish key partnerships with states, counties, cities, tribal nations, academia and the private sector to increase data availability" (FGDC, 2013). From a practical perspective figure 4 illustrates the internal components of an SDI.

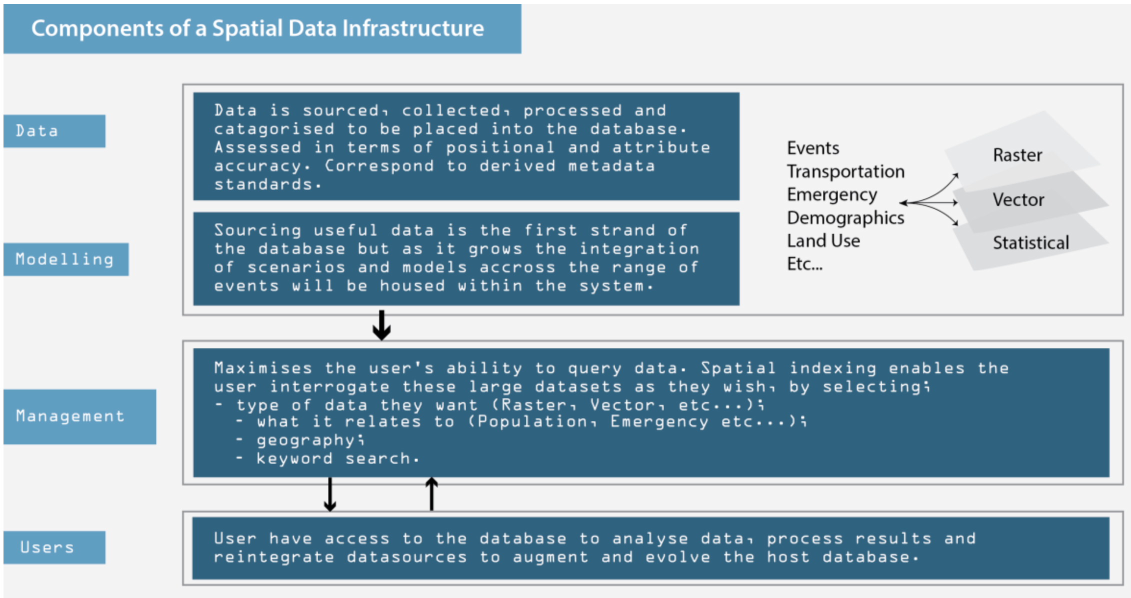

Figure 4 Components of an SDI (Source: After Author adapted from INSPIRE, 2013)

The INSPIRE directive established broad framework for a Spatial Data Infrastructures (SDI) to be held as a template for the purposes of European Community environmental policies. Its principal goals relating to the exchange of data, interoperability and data re-use, for effective governance and policy making purposes (INSPIRE, 2013). Data is typically classified into thirty four "spatial data themes" (Figure 5) which cover the 'basic' spatial building blocks. Not all themes are relevant and depend on the purpose of the SDI. Within emergency management the purpose of the SDI is to provide timely and relevant information to stakeholders for a range of reasons, namely;

- Intelligence gathering and analysis supported for Emergency Management
- Simulated projections of surge capacities (population data) and resource allocations.
- What-if models to predict the likelihood of disasters.
- Integrate existing data to formulate of up to the minute strategies and tactics to address specific threats.
- Automate and integrate data models, allowing for the generation.
- Support the generation of the situation operational picture and projected evacuation or explosion plume models.
- Identify vulnerable groups (rest homes, mentally ill and disadvantages areas) and potential impact to plan for recovery.

- Estimate potential cost in losses of buildings, infrastructure and help create a plan for recovery
- Enable baseline reporting before and after impact.

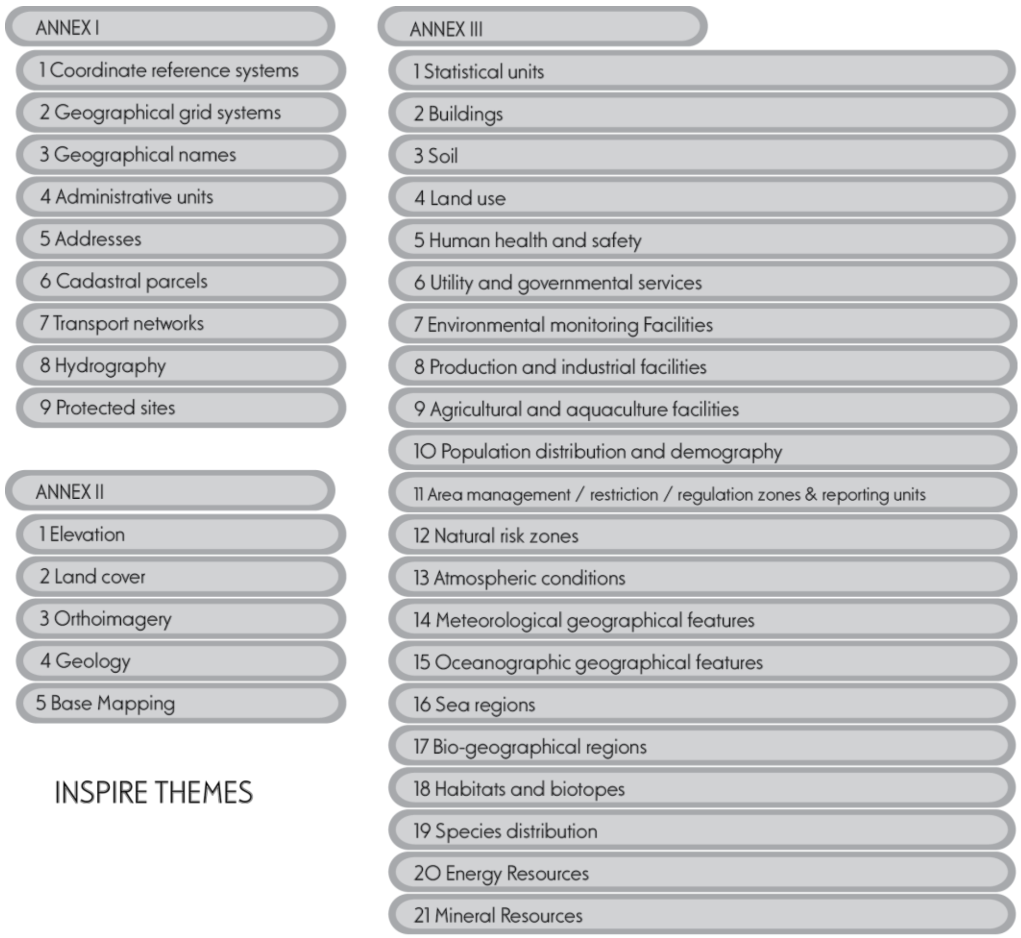

Figure 5 INSPIRE Themes (Source: After Author adapted from INSPIRE, 2013)

An SDI can be implemented at different geographical scales. Well-known examples of SDIs are the Global Earth Observation System of Systems (GEOSS) (GEO Secretariat 2005) and the United Nations Spatial Data Infrastructure (UNSDI) (Henricksen 2007) at the global level, and the Infrastructure for Spatial Information in the European Community (INSPIRE) (European Commission 2007) at the regional level. At the sub-national level the example of Spain is singular as most provinces have built up their own SDI, e.g. IDEAndalucia, GeoEuskadi, Catalunia. Some of these systems have been created for general usage by the public, others have been developed with specific technical users in mind.

Although an SDI can be broken into the 3 strands previously mentioned (technologies, policies and people), this study focuses on the technology component. Theory on the policy and communication networks (people) has been explored at great length and does not impact on content of this study.

2.4 THE ROLE OF DATA IN DISASTER MANAGEMENT

Disasters both natural and man-made create a dire need to rapidly collate, comprehensive and reliable data on the nature, extent and actual consequences of an event. Gathering and communicating data to stakeholders is the lifeline of any disaster response. It is critical for all parties involved to understand the situation and its expected evolution. This comprehension is needed to implement an effective and efficient recovery plan and bring relief to those affected who need it. The capacity to effectively acquire, collate and share data is essential to this comprehension, and is the primary enabler for coordination between stakeholder parties.

When looking at the role of data in disaster management, it is important to understand how stakeholders use data throughout the various phases of a disaster, and what the objectives are to which data contribute. For this, first a further look is taken at the concept of data itself, and then the use of data is examined in the different phases of a disaster, with a specific focus on needs assessments.

2.4. Challenges to Effective and Efficient Use of Data in Crisis

In spite of the considerable progress that has been made over the course of the last decade to address inefficiencies in the crisis recovery and reconstruction process and to enhance collaboration between key stakeholders, data sharing and the coordination of information (across all stages of the crisis cycle) continues to be considered problematic by those involved in crisis response. A number of research investigations attribute the inability to share and effectively coordinate information to the dynamic and volatile nature of a crisis environment (Kapucu, 2006)(Aboueljinane, *et al*. 2013)(Leifler, 2008). Nonetheless the need for stakeholder collaboration within a crisis scenario is undisputed whilst the value derived from a robust and credible data rich evidence base has been shown to contribute to a more effective and efficient response strategy as well as informing a more sustainable recovery and reconstruction process (Kohli, R. and Devaraj, S. 2004). As such there is an onus on key stakeholders to explore opportunities for greater integration of data resources within the confines of crisis planning and to actively encourage and promote the sharing of information.

It is judged from experience of previous crisis incidents, that the real obstacles to emergency response and crisis management are not necessarily the lack of data but the fact that huge amounts of data is stored in different formats or is held by disparate stakeholder groupings (Donkervoort *et al*. 2008). Moreover, bottlenecks in data transfer are in most cases attributable to the lack of data standardisation and the lack of interoperability between both organisations and key data sets (Kumar, S. And Havey, T. 2013). Creating synergies across the various phases of the disaster cycle and between the key actors very often necessitates the reshaping of operational processes, methods of interaction and general interfaces, building shared pools of data, in addition to better sharing skills, methods and tools. As a consequence the ideology of more efficient and effective data utilisation within the confines of crisis recovery and reconstruction is it not without complexities.

2.4.1.1 Data Accessibility and Availability

The unrestricted availability and accessibility of data is essential for the realisation of interdisciplinary understanding and for developing situational awareness of the impacts, ensuing risks and potential cascading consequences of disaster incidents. Invariably the depth and completeness of the data available will vary across different points in the disaster cycle but the availability of data and the capacity to access that data in a timely manner will have a major bearing on capacity to inform decision making premised upon a credible and robust evidence base (Hamedi, M., *et al*. 2012). Kohler et al. (2006) highlight that the financial commitment and completeness of the data, as well as availability and usability can fluctuate significantly from country to country and with respect to the purpose for which they were collected. The underpinning data necessary to inform all stages of the disaster and recovery process are for the most part not held centrally. In many European countries key datasets used to inform reconstruction and recovery are collated by federal, regional or local authorities (Kohler et al. 2006).

Research institutes also have access to rich data repositories whilst various data sets deemed critical to informing the decision making process are held by non-governmental and commercial or proprietary providers (Fogli, D. and Guida, G. 2013). A further dynamic in terms of data accessibility is Intellectual Property Rights which often act as a barrier to the integration of different data sources, or at the very least raise red-flags with respect to licensing arrangements, usage rights, and ensuring future continued collection of same data. The principal barrier to open data sharing is nonetheless the arcane format in which data is collected and presented on government computers and the inability to share this data easily with other actors involved in the recovery and reconstruction process or the wider public (Adeyemi, *et al*. 2013). The ability to capitalize on advancements in ICT which advocate data sharing is to a great extent dependent upon both companies and governments improving how they share information. For example, in the US following the aftermath of Hurricane Sandy it was discovered that regulations and policies needed to be amended or altered to allow for certain collaborations with public data (Aktas, *et al*. 2007). This is often one of the hardest changes to make, but by illustrating the benefits to the State and the citizens, resolutions can be found. While many government agencies and first responder systems may need a certain level of security and firewall to the outside world, speedy and open access, powering the ability of users to share and communicate information, accelerates relief efforts.

2.4.1.2 Data Sharing and Integration

Post-disaster evaluations conducted over the course of the last decade highlight deficiencies in data sharing between organisations, levels of incompatibility in work practices, misalignment between needs and recovery actions, as well as short-sighted decisions on funding and the courses of action (Dorasamy, M., et al. 2013)(Arora, et al. 2010). Previous poor experiences in information pooling, lack of trust, and resource constraints are some of the features identified which undermine information and knowledge exchange. Reviews of crisis responses initiated over the course of the last decade highlight a shift to the use of multi-faceted methodological approaches in order to better understand information exchange in acknowledgement of the complexity of contemporary decision making and the dynamic environments, diverse social contexts in which crisis responders operate (Schryen, G. And Wex, F. 2012). It is apparent that whilst considered progress has been made in advocating stakeholder collaboration and information sharing, the continued absence of a robust interoperable data framework which can serve as an evidence base to inform strategic decision making within vibrant environments such as those encountered during and in the immediate aftermath of a crisis event has contributed to unnecessary protracted recovery timelines as well as inefficiencies in resource allocation (Neef, 2013).

There is a plethora of governmental, non-governmental and charitable organisations involved in the recovery and reconstruction process and each will have different constitutional remits, resources, response rates and capabilities (Yang, L., et al. 2013)(Aschenbruck, et al. 2009). Moreover each will have its own information resource with varying degrees of appropriateness to a given crisis and location (Deak, G. et al. 2013). In many ways this replicates the classic arguments for the allocation of resources – either through the market (in an unplanned manner) or in a more managed framework (organised by government or a lead organization, such as the United Nations). In the context of a crisis event all humanitarian or physical support bodies may respond individually and there may be a lack of co-ordinated working, confusion, over-lap or under-lap of engagement, and wasted effort and resources (de Lanerolle, T. R. et al. (2010). This may be characterised as a non-strategic response agenda. The alternative is for a more managed approach which seeks to provide a more holistic response through strategic thinking and co-ordinated actions (Mays et al. 2013).

There is a general issue relating to the wide and diverse organizations with potential to respond to a crisis and a specific question relating to the harmonisation of data and information. First, there is an organizational agenda required to ensure that the composition of bodies involved in the recovery and reconstruction process are integrated in such a way as to provide an efficient and effective response(Friedrich, F., et al. 2000). There is an extensive literature base delineating the debates and ideologies of data integration premised around the ideologies of addressing inherent institutional and administrative inefficiencies (Aboueljinane, *et al*. 2013)(Zerger, A. and Ingle Smith, D. 2003). In crisis response contexts enhanced sharing of data is considered the mantra to facilitating integrated working of the various bodies within crisis and recovery decision making. In practical terms: it may require the implementation of non-traditional arrangements such as *contractualism* or '*concertation'* that have been advocated whereby formalised agreements are put into place to secure desired outcomes (Vincent-Jones, 2000; Pichierri, 2002). In the opinion of Lloyd (2008) such collaboration and information sharing arrangements depict a rethinking of the ways in which more effective integrated actions can be achieved.

An extensive body of literature exists concerning the creation of information, its management, its interpretation and use (Gerlak et al. 2011). Complexity is present in the data characteristics, user dimensions and system design aspects; and the relational dynamics between them. Additionally, it is important to recognise that not all the recovery response and planning bodies may be physically involved in the specific response (maybe not having the appropriate skills or competencies for that specific crisis) but can make available their information resource to support the response programme (Wex, F. et al. 2014). There are nonetheless challenges relating to the technical and organisational aspects of information management and decision making; there is a need to understand information-seeking behaviours and knowledge construction; and a need to better appreciate and understand ways of facilitating information sharing and knowledge exchange across an increasing diverse range of mediums/sources (Rolland, E. et al. 2010). It is clear from the existing literature base that there is a need for the deliberate coordination of data and information, and for information sharing, in order to support strategic decision making and improve the efficiency and effectiveness of disaster response strategies (Wiedener, M.J. and Horner, M.W. 2011)(Rodríguez, J.T., et al. 2012). There are a number of theories to analyse and explain information seeking and retrieval behaviours, yet there is no accepted methodology which prescribes how an information and ideas exchange might operate; this is contingent on the particular context and conditions involved (Sen, A. et al. 2012)(Liberatore, F. et al. 2014).

The aspiration of crisis response managers is to develop a comprehensive needs picture across the different phases of the recovery effort in order to initiate a sustainable recovery and reconstruction programme. The development of matrices of community needs, recovery activities, and their corresponding acting parties support the identification of duplication and missing efforts and priorities (Miniati, R., et al. 2014). This requires information sharing from whole of community sources and interoperability in multiple ways. A comprehensive picture of community needs is built up by community members and is grounded in their short and long-term needs for sustainable well-being (Antonopoulou, E. et al. 2010). Accountability of recovery efforts can be supported by making explicit relations between identified community needs, recovery activities and involved organisations explicit. Oloruntoba (2013) asserts that a comprehensive community needs picture consists of information relating to, for example;

- drivers of the crisis,
- scope of the crisis,
- profiles of affected community,
- the needs of community members in the affected area,
- local and regional capacities for recovery and reconstruction,
- capacities outside the area,
- coverage of community needs and gaps,
- strategic priorities.

As time progresses, the focus of recovery will shift from short to long-term and the community needs and action plans will need to shift accordingly. By maintaining explicit relationships between these pieces of information, recovery objectives can be formulated that can be monitored through time as identified needs are met and new ones emerge (Hadiguna, R. A. et al. 2014). This approach facilitates progress monitoring, improves accountability, and stimulates unity of effort because the baseline picture is made through a collaborative effort of all involved parties.

Evaluation of crisis response has highlighted the inability to integrate and capture data availability as one of the more pertinent issues within modern disaster management. The earthquake in L'Aquila, Italy in 2009 highlighted some important difficulties which can arise if information is conveyed in a manner which could be open to interpretation. Prior to the earthquake, conflicting reports on the levels of danger posed to certain regions have been described. A gap in expertise and decision making capacity was reported in relation to the early warning system – scientific information provided by experts on levels of risk were not well understood by local authorities who were unsure about how and when to act (Fearnley, 2012). In addition, local actors did not advise scientists on the local conditions which could provide more certainty on the levels of risk posed to certain communities (for example, many buildings in L'Aquila were not structurally sound). Consequently, a number of areas did not act at all and suffered huge damages from the earthquake as a result. The ability to combine scientific knowledge (forecasting, risk assessment etc.) with local knowledge (social, economic, political and cultural factors specific to the at risk population) to inform decision making is critically important (Fearnley, 2012). Thus, enhancing open and transparent networks of communication among decision makers is a key challenge within disaster management.

2.4.1.3 Harmonisation and Interoperability

Di Maio (2008) endorses the view that advances in ICT technologies, specifically the internet and related web-based applications represent an ideal universal, real-time and widely distributed platform which is well matched to optimise data exchange, in order to bolster the flow of information to key decision makers involved across all elements of the recovery and reconstruction process. However, one of the key challenges facing crisis response managers is the lack of data harmonisation and the interoperability of data sets across different national contexts as well as between key stakeholder groupings. Harmonisation refers to the standardisation of data so that they can be matched with other data and information regardless of the format (Villa et al, 2008).

Interoperability is the ability of products, systems (organisational or technological) to work together in order to accomplish a collective goal (Villa et al. 2008). The major issue in data harmonisation within the confines of crisis response is that currently there is no framework setting common, unifying, data collection and production measures and a proper agreed exchange format between organisations. Meanwhile, different domain terminologies are regularly used by the various crisis information systems. This presents a challenge to efficiently exchanging information as frequently the semantics of the data can be dissimilar and quite difficult to assimilate (Wendt, K., et al. 2013). For example, the term 'Person' has different meanings, or more layered meaning depending on usage - a ‘displaced person’, ‘recipient of aid’, or ‘victim’. Within this premise semantic interoperability is a key challenge to the interoperability of data within the confines of crisis response and recovery. Moreover, that data is a critical building block of information systems including SDIs, and thus if they are not appropriately supported with meaningful data, it can render them useless.

Shaw et al (2013) highlight that the increased use of information systems and data within crisis management makes the challenges of information sharing and data interoperability increasingly important. The Haiti Earthquake in 2010 is considered a watershed in the application of disparate and remote forms of Information and Communication (ICT) to inform the recovery and reconstruction process (Hattotuwa and Stuffacher, 2010). Nonetheless, the earthquake in Haiti served to highlight a series of deficiencies in the collation, analysis, interpretation and transfer of data within dynamic, highly volatile situations. Communities affected by the earthquake for the large part remained passive recipients of information, having to deal with, amidst significant trauma, competing information on aid delivery and services. Equally, the bulk of people affected by the disaster would be beyond the radar of ICTs (Hattotuwa and Stuffacher, 2010). The Head of the UN OCHA, expressed frustration at the relief effort citing ‘only a few relief clusters have dedicated cluster coordinators, information management focal points and technical support capacity’. Beyond the UN observations, significant concerns were expressed about the coordination and collaboration between civil and military responders and the lack of data and information sharing as consequence of the incompatibility in datasets as well as the capacity to capture (and indeed place trust in) unstructured data being delivered through new forms of media (Yang, L., et al. 2013).

Haiti has been described as a ‘technological learning environment’ within the confines of a dynamic crisis environment. In the immediate aftermath of the earthquake a series of information platforms were initiated in order to utilise the pervasive power of the internet and mobile technologies, including social media to assist in informing potential relief and response efforts being made (Varshney, U. et al. 2014). The USHAHIDI platform facilitating the collation of distributed data via SMS, email, or web and visualise it on a map or timeline was deployed in order to ascertain the needs of affected communities in the field. SAHANA, a web-based collaboration tool designed to address coordination problems amongst actors involved in the relief effort was also deployed utilising crowd sourced data in discerning the precise coordinates of key infrastructures including medical provisions. USHAHIDI and SAHANA complemented the UN's OneResponse platform which served as the key portal in terms of situational reports, updated contact information and mapping data. Pertinently, almost all relief agencies involved in Haiti including military personnel utilised social media and mobile technologies to help organise, synchronise information generated by the affected communities (Hattotuwa and Stuffacher, 2010).

Reviews of crisis incidents over the course of the last decade highlight the increasingly important role of ICT systems in informing the response and recovery process. Moreover, there is increased recognition amongst the responder community that in the prevailing 'network age' (OCHA, 2012) communication and production of data is no longer a 'one way street' – humanitarian organisations and policy makers responsible for the initiation of disaster preparedness strategies and for the coordination of recovery and reconstruction operations are increasingly embracing the benefits of not just disseminating information but having a dialogue and receiving information from affected communities - those who previously were just information recipients (Rodríguez, et al. 2010). The advancement in ICT to enable two-way communication flow within the advent of a crisis incident is widely considered a positive development within the disaster management literature. Nonetheless, concerns have been raised around the reliability of the information presented by affected communities as well as the capacity of affected communities to understand and act rationally on information from responders within highly volatile situations. In order to be useful, information must be accurate, trusted, and easily understood by both the affected community and the disaster responders (Vescoukis, et al. 2012).

Whilst the Haiti earthquake for example served to highlight the positive benefits offered by crowd-sourced information there are a number of risks which also stem from this innovative aspect of modern communication technology (Kulawinak, M. and Lubniewski, Z. 2013). Anyone who has access to mobile or online technologies can contribute to ongoing dialogue and preparation of solutions within a crisis period – this has major implications in terms of verifying and validating the data. Data from social media can be especially unsound and requires some form of verification tasks to be carried out in order to determine validity. Moreover, the potential for a 'tsunami' of information that can result from harnessing social media channels post-disaster, has the potential to overwhelm any envisaged platform (Yi, T. And Zhu, Q. 2014). Sorting through the 'noise' of this vast amount of data whilst serving to overcome historic barriers in the form of 'information vacuums' presents new challenges in terms of the capacity and effectiveness of data management systems as well as the ability to integrate and harmonise of both structured and unstructured datasets to inform crisis response. The accuracy of information generated from crowd sourcing platforms is nonetheless often low; sometimes less than a third turned out to be accurate. Additionally, the tendency of citizens to exaggerate under extreme stress should not be underestimated, nor should the potential service that crowd sourcing will serve in future operations as citizens learn how to use social media (Yates, D., and Paquette, S. 2011).

Harnessing the potential benefits to humanitarian efforts of advances in ICT and mitigating the risks that they pose will be a key challenge for crisis response agencies moving forward. Large scale disaster incidents such as the Haiti earthquake are prominent examples of how crisis response efforts are evolving to leverage the efficiencies offered by the internet in the area of real time communication among agents and stakeholders. Nonetheless, OCHA (2012) reports that current practice has not been able to take full advantage of the new technologies and partnerships offered by this 'network age' to share, manage, understand and then act on information in an effective and timely way. Indeed, post-crisis evaluations of crisis responses over the course of the last decade would suggest that whilst the new sources of information available as a result of new technology, these new sources of 'information' are not being effectively harmonised with more traditional and structured data sources (Suh, W., et al. 2014)(Yates, D., and Paquette, S. 2011)(Gupta, A. and Sharda, R. 2013). It is apparent that today's information systems used in the field of disaster management are often not as open and extensive as needed to consolidate the complex data sets and the different systems described above for solving tasks and questions based on complex workflows and scenarios. Interoperability as well as application-oriented integration of methods, data and systems must be improved. This could be realised by designing distributed software architectures, which enable and support flexible and interoperable keeping, integration and more effective networking.

2.6 RESEARCH IN PRACTICE - CASE STUDIES

The need for enhanced integration of data sources for sharing of information between actors involved in the crisis recovery and reconstruction process is not contested. Deliberations do prevail however around the means by which this can be most effectively achieved (Ivgin, M. 2013)(Huang, M., et al. 2012)(Liberatore, F. et al. 2014). Additionally, evaluations and observations recorded from crisis events over the course of the last decade, highlight data provision and the capacity to transfer and communicate data in a manner which is both timely and conducive to informing decision making in the area of the recovery and reconstruction process. This offers the greatest scope for enhancing the proficiency and efficiency of relief efforts. Perhaps, because data collation and information flow transcends all phases of the recovery and reconstruction process, or because it cascades all 'response clusters' it has not been afforded the depth of exploration or developed understanding other areas of the crisis cycle. More needs to be done to champion the role of data and information sharing in terms of the contribution to the response, recovery and reconstruction process. At present, the quality of data provision, the transferability and interoperability of data is not recognised with the levels of acclaim or afforded the same recognition as other facets of the response, recovery and reconstruction process. Even though in many instances it was the availability of the data which dictated the response strategy and intervention measures, the true value of timely, credible data - it would seem - only materialises within the confines of an 'information vacuum'. Notwithstanding the barriers, considerable progress has been made in recent years pertaining to the accessibility and interoperability of data – much of which forms a critical underpinning data repository for informing crisis recovery and reconstruction.

The theory behind a well-working system has been established throughout this literature review, however the study recognises that the practical development and implementation of SDIs is more challenging. Moreover, that with implementation comes further challenges which cannot be assessed in academic literature. In this regard, the study will assess the progress made in research initiatives (like the Seventh Framework Programme for Research (FP7) 2007-2013, within the European Commission), as well as commercial applications in the emergency management space (Vector Command Centre). This assessment will seek to establish the realistic approaches to development with each case study highlighting their measurable goals as well as lessons learned.

2.6.1 INSPIRE Directive

On a European scale, the INSPIRE SDI is the principal source for all governmental spatial data. The INSPIRE directive came into force on 15 May 2007 and will be implemented in various stages, with full implementation required by 2019. The main aim of INSPIRE has been the creation of a cross boundary, pan-European Union Spatial Data Infrastructure (SDI) to facilitate the sharing of GI among all spectrums of government and improving accessibility of GI to European citizens (Local Government Group, 2010). Under INSPIRE, the 27 nations of the EU are required to undertake a number of changes to their current data capturing methodology to ensure consistency, accountability and comparability of approach (Rao, M. et al. 2007). These requirements include:

- Make available and interoperable, metadata that detail the underpinning elements of spatial datasets and services so that they can be shared.
- Implement network services to facilitate an enhancement of awareness, access and use of spatially enabled data.
- The removal of barriers that have in the past prevented the sharing of GI between different public sector bodies.
- As part of this INSPIRE Directive the Commission is required to establish a community geo-portal and the Member States shall access to their infrastructures through the geo-portal.

The INSPIRE SDI in its current form must cater to an extremely large audience (that being the entire EU on any range of spatial themes). Having to cater to this many potential users (both technical and non technical) has created a variety of issues. For example, an analyst entering the geoportal must wade through vast amounts of data to find necessary data, this data could be in a format not suitable for his/her working, and/or once download and interrogated this data must undergo further post-processing steps before ready to use. In emergency management this inefficiency takes valuable time away from responding efforts.

2.6.2 S-HELP

The S-HELP project is a 3-year, European FP7 funded plan aimed toward advancing the knowledge base required for the development of a range of Decision Support (DS) tools and a Decision Support System (DSS) for the management for all of Emergency Medicine activities. The central aim of the S-HELP project is to develop and deliver a holistic framed approach to healthcare preparedness, response and recovery. S-HELP is a people, process and technological solution to emergency situations (S-HELP Project, 2014).

The S-HELP Decision Support System (DSS) seeks to bring benefits to emergency healthcare management, from learning and preparing for emergency incidents and analysing threats, to post evaluation, reporting and logistics management. It provides a mechanism to assist stakeholders and end users to work together for co-ordinated, effective, evidence based decisions at all stages of emergency management (EM). It therefore plays an essential role in the response to emergency situations that in many cases have negative impact on human's health.

A base component of this S-HELP framework is the Spatial Database Management System (SDBMS). The S-HELP SDBMS aims to provide an infrastructure to support access to key datasets to inform and guide decision making during all stages in the emergency management cycle. Assembly and integration of these key 'data layers' into a centralised and usable repository was identified as a key resource of the S-HELP concept to inform later decision support analytics.

The deliverable comprises of two sub-tasks -

- A SDBMS to house and manage the spatial data which offers a front-end User Interface (UI) component to the end user enabling better interaction with data stored within it. The SDBMS provides a central repository of data for application and analysis relating to the scenarios in other project workpackages;

- Data Scoping and Collation - the SDBMS will be populated initially with a large number of datasets from a wide variety of sources. These data sources will grow and advance over the lifecycle of the project. In the first instance, data has been sourced and processed, with respect to positional and attribute accuracy and matched with derived INSPIRE compliant metadata standards before integration into the database for project use (S-HELP Project, 2014).

The output of this deliverable is the S-HELP geoportal, a web-based GIS platform that provides access to, and visualisation of, geospatial data and associated metadata collected for the SHELP project. The solution attempts to take the INSPIRE concept and principles and apply them to the emergency management arena specifically. This application has optimised the workings of an SDI in terms of the content of the data, data formats and of data segmentation (ability to select and query only relevant disaster data based on spatial location). These facilities reduce the time required by first responders in generating common operational pictures by allowing analysts to access, query and analyses relevant data faster.

2.6.3 Copernicus Emergency Management Service

In the Seventh Framework Programme for Research (FP7) 2007-2013, the European Commission, in partnership with the European Space Agency, set the foundation for the development of the Global Monitoring for Environment and Security (GMES). The GMES initiative included a budget of €1.2 billion for the development of services that would support both the environment and security, with particular focus on the atmosphere, emergency response, land, ocean and security. In a security context, the benefits of this research agenda were designed to enhance the quality of life in Europe through utilising earth observation satellites and ground based systems to better understand security preparedness and response capacity. It was designed to improve prediction monitoring and assessment capabilities of member states of Europe, through providing a platform to be better prepared for security issues such as man-made and natural disasters and respond more effectively and efficiently in emergency situations.

The Copernicus emergency management service provides all actors involved in the management of natural disasters, man-made emergency situations, and humanitarian crises with timely and accurate geo-spatial information derived from satellite remote sensing and completed by available in situ or open data sources. The mapping component of the service

(GIO EMS - Mapping) has a worldwide coverage and provides maps based on satellite imagery.

GIO EMS-Mapping consists of the on-demand and rapid provision (hours-days) of geospatial information. This information supports emergency management activities immediately following an emergency event. The service is based on the acquisition, processing and analysis, of satellite imagery and other geospatial raster and vector data sources. There are three kinds of standardised products following a set of parameters, which the user can select when requesting the service:

- Reference maps provide a quick updated knowledge on the territory and assets using data acquired prior to the disaster
- Delineation maps show the extent of the disaster (e.g. flood extent) superimposed on a post-event image
- Grading maps provide a graded damage assessment (e.g. highly, moderately, not affected areas) over the impacted zone.

Despite the success of the service and the crucial support it provides to the actors involved in the management of emergencies, Blistanova, et al. (2014) notes that the provision of EMS-Mapping is hampered by a number of limiting factors stemming from the technical limitations of Earth Observation (EO) sensors on board the current fleet of satellite platforms. These limitations are related mainly to the spatial resolution (GSD: Ground Sample Distance) and temporal availability (orbital passage over are of interest) which often prevent adequate imagery from being received in the very short time period called for by the emergency situations. Such supplementary information can be instrumental in supporting the analysis of satellite imagery and in making the final product more authoritative and useful for the final user.

2.6.4 COBACORE

The Community Based Comprehensive Recovery (COBACORE) project is a 3-year, European FP7 funded plan which aims to support common needs assessment and recovery planning efforts in complex multi-sectorial, multi-stakeholder crisis environments by building upon the community as an important source of information and capabilities (COBACORE, 2013).

The COBACORE project is attempting to develop a platform through which greater cross-jurisdictional and joined-up delivery mechanisms can enhance the preparedness and response model to disasters (both natural and man-made) at different geographic scales (national, regional and community). In order to do so, it seeks to encourage and provide for greater community engagement and involvement in the needs assessment process. Greater community involvement in needs assessment processes is a demand that is widely highlighted as being a fundamental requirement in delivering more effective reconstruction and recovery models and something which has been lacking in previous needs assessment platforms (COBACORE, 2013). The COBACORE platform is a web-based, information-driven workspace that is readily accessible from mobile devices, operational centres and remote locations. The platform will have different interfaces for the different stakeholders in the damage and post-crisis needs assessment community, tailored to suit user-specific demands and capabilities. The platform is a set of interconnected modules and mechanisms that maintain three state models: the community model, the context model, and the needs model. The information contained in these models is accessible for users through a collaborative workspace, customized to suit their needs and preferences. The models are built up post-crisis through collected data from the affected area, through collaborative manual completion and maintenance, and through use of existing information sources, and based upon generic frames that are developed in advance for different scenarios.

The COBACORE system adds a new perspective to existing applications of SDI in emergency management. The project attempt to add ground-up approach to data gathering by creating a framework through which first responders and communities alike can upload, interrogate and contribute to the common operational picture. It is expected that this approach will generate rich streams of data from on-the-ground sources the intimation being that it will assist in better decision making. The approach however raises issues of data quality for a number of authors (Chatterjee, S. et al. 2009)(Chen, A. et al. 2011). With no quality assurance testing inaccurate data could slow down response efforts.

2.6.5 EDEN (Emergency Development Environment for Rapid Deployment Humanitarian Response Management)

Eden is a flexible humanitarian platform with a rich feature set which can be rapidly customized to adapt to existing processes and integrate with existing systems to provide effective solutions for critical humanitarian needs management either prior to or during a crisis. Sahana Eden's features are designed to help Disaster and Emergency Management practitioners to better mitigate, prepare for, respond to and recover from disasters more effectively and efficiently. Sahana Eden can provide valuable solutions for practitioners in Emergency Management, Humanitarian Relief and Social Development domains.

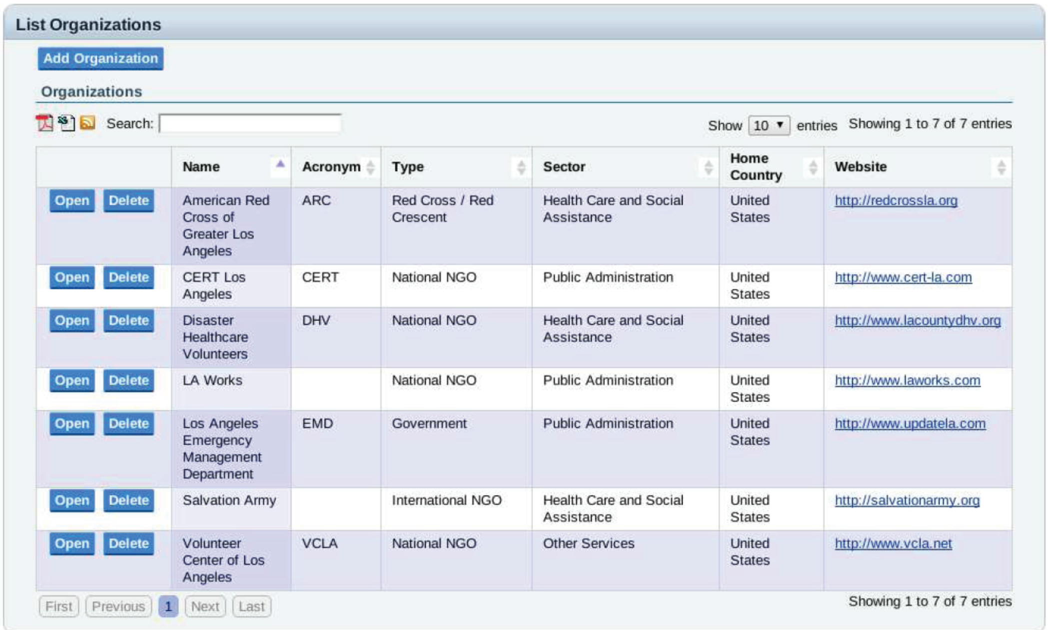

Figure 6: SAHANA Eden Web Interface

Eden software was first deployed for disaster responses purposes following the 2010 Haiti earthquake for public use and also to support the food distribution programs of the UN World Food Programme. It contains a number of different modules which can be configured to provide a wide range of functionality specifically in the SDI space. The software can manage assets such as vehicles, communications equipment and generators; tracks where they are, who they have been assigned to, and what condition they are in. This ensures that assets are used effectively and efficiently. Collects and analyses information from assessments to help organizations more effectively plan their disaster management activities. Data can either be entered into an interactive web form or imported via an Excel template. It can plan for different scenarios, including recording what human resources, assets, facilities and tasks will be needed to effectively respond. Additionally, Sahana Eden has fully integrated mapping functionality which allows any location-based data to be visualized on a map. Maps provide situational awareness which is essential when either planning to prepare for or respond to a disaster.

2.6.6 Current COMMERCIAL Incident Management Tools

This section investigates commercially available tools with a specific focus on the spatial information aspects of their infrastructures. The table overleaf provides an overview of some of the most commonly used tools and their key functionalities. These commercially available tools were compared, for preparedness and for response to an emergency.

Within currently available commercial systems there appears to be a very strong focus knowledge management and data warehousing. This emphasis in a number of cases (Adashi, Mapxy and IMASS) has led to very clunky overly complicated user interfaces that are difficult to use. Hosack (2012) predicts that the research behind knowledge management DSS and data warehousing will merge, and the motivation will shift toward coming up with more effective ways to facilitate end-users interaction with obtainable data. Moreover, that as the inherent intricacies of decision-making increase alongside the greater accessibility of data, there will become a need for more complex, more data intensive and more analytically-based spatial data infrastructures to be aligned with knowledge and DS tools.

Resource management modelling is strongly supported by current vendor systems. This facilitates responding organisations in their efforts by consolidating available resources into manageable units which can be deployed from one central command unit. In some cases (Mapya, WebEOC, NC4) there is a need to incorporate logistics models to assess needed resources and their positioning. Data must be mined from multiple sources such as from end users, ordinance survey maps, global positioning system (GPS), open source spatial data and healthcare systems in order to provide a comprehensive picture of the (emergency) landscape.

Training is supported by the majority of the reviewed tools. However, most fail to track end user training, and therefore will miss opportunities to refresh and retrain responder knowledge. Equally, another important requirement of emergency tools should be the post evaluations. This process facilitates the generation of lessons-learned to facilitate future improved decision-making. Eight of the fifteen tools analysed address this, but only four cater for gap analysis to incorporate post-crisis information. Both of these features are key to growth of SDI in emergency management.

There is a lack of custom model integration across all the platforms. No inherent ability is afforded to reintegrate or adapt existing models or algorithms back into the system. Equally, there is limited functionality with regards to feature manipulation. None of the commercial software's have the ability to export custom packets of information or to export this data in any format.

Common Features	Vector Command	Mapyx Ltd	SAR Technology Inc	ESRI	Firehouse Software	Adashi	WebEOC	NEMISIS	NC4	D4H	Intergraph	Fortek	Athlas/AIMS	IMASS STEPS	National Extranet
Resource Management Modelling	✓	✓	✗	✗	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✗
Threat Analysis	✓	✗	✗	✓	✓	✓	✗	✗	✓	✓	✓	✓	✗	✗	✗
Training Methodologies	✓	✗	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✗	✗	✓
Custom Model Integration	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Predictive Tools	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓	✓	✗	✗	✗	✗
Import Data	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓	✓	✗
Custom Data Select / Export	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Modular Based	✓	✓	✗	✗	✓	✗	✓	✗	✗	✓	✓	✓	✗	✗	✗
Mobile Based	✓	✓	✗	✓	✓	✗	✗	✗	✗	✓	✓	✓	✗	✓	✗
Cloud Capability	✗	✗	✗	✓	✗	✗	✓	✗	✗	✓	✗	✗	✗	✓	✗
Mapping using multiple information sources	✓	✓	✗	✓	✗	✗	✓	✗	✓	✓	✗	✓	✓	✓	✗
Multiple data format options	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Map Overlays	✓	✓	✗	✗	✓	✓	✗	✗	✗	✗	✓	✓	✓	✓	✗

Figure 7: Functionality of Commercial Tools for Disaster Management (Source: After author)

Each of the commercial tools considered for the literature review is tightly aligned to a very specific objective, or set of objectives. The purpose built nature of the systems means they do certain things extremely well, but aren't extensible to a range of disasters, or procedures to handle disasters. This has resulted in a retainer type arrangement between host organisations and the commercial organisation whereby custom features and modules are added to existing systems and they grow in a bespoke fashion. The study has also determined a number of areas in where there is a deficit in terms of user functionality which have been overlooked within commercialised development. Moreover, that some of these deficit areas are considered crucial within the EU funded research projects reviewed for this thesis. It most cases it is unclear if this is down to compatibility issues, unrealistic or just an oversight.

2.7 CONCLUSION

Data accessibility and availability, data sharing and integration and harmonisation and interoperability are judged to be the most significant factors in creating a sustainable SDI for emergency management. In creating sustainable systems that embody these qualities, more research is required from a practical development perspective. A review of academic literature on the usage of data in emergency situations has highlighted a number of distinct facts. It has been found that academic studies on the topic are quite assertive in their theoretical underpinnings, but stop short of building any functional systems or applying this theory in practice. This raises two immediate problems in this author's judgment:

1) **Concept Theory Vs Application Development. F**or example, in academic works it is frequently remarked "how important it is to establish efficient un-congested real-time data feeds". Conclusions like this do not go far enough to see the technical limitations of attempting to establish what has been set out in theory (or, more specifically, the additional problems that are inevitably encountered when entering the practical development space).

2) **Context.** SDIs for emergency management are very different to SDIs in any other context. There are inherent constraints of working with data in disaster situations and for disaster situations. No other SDIs deal with the following latent restrictions to a similar extent:

   a. **Web-Based Systems**

   Most SDIs have migrated to the web. This brings with it a number of challenges. As the web has developed, the functionality of web-based systems has augmented. Advances in web-based languages, like JavaScript, new libraries for geospatial interaction have been created to enable users of a system to have increasing ability to interact with systems.

   b. **High Speed Data Transfer**

   Large volume of spatial data is being transferred from one location to another. Outside of emergency management this is less impactful, analysts and decision makers who utilise these services do so using high speed internet. By contrast, all tiers within a disaster response effort must have the same reasonable access to data services (e.g. Location A may have high speed networks, but location B may be in and earthquake torn region with minimal or no internet connection or infrastructure). A strategy for disaster response is only as strong as its weakest link, so if there is to be a reliance on SDIs in the future they must be able to bypass this or create contingencies for effective communication under all circumstances.

   c. **Data Segmentation**

   Data is collected in spatial units. Those units could be local, regional, national or international. Depending on the response efforts, size and scope of the disaster, perhaps only a small segment of these data aggregation scales is needed. Following on from the first point on internet speed, data streams must be as efficient as possible. In this regard, SDIs for emergency management need to be streamlined to facilitate data extraction based on spatial querying (i.e. cookie cut out relevant data to minimise data requirements). A user will seek to extract the minimal amount of data that can be used to make a decision. Depending on the type of scenario and the type of analysis being done there is any number of requisites on data if choosing environmental, social, or economic data.

d. Devices

The nature of the device using these systems has changed over the past decade. Mobile phones, tablet, laptops have become an important consideration in developing modern interoperable systems. In emergency management building modern responsive applications across all platforms has been deemed (Fogli, D. And Guida, G. 2013)(Deak, G. *et al*. 2013) to assist in collaboration between relevant stakeholders in a disaster response.

e. Data formats (Feature Manipulation Engine)

Spatial data is held in an array of formats. These formats depend on the discipline the data relates to, amongst other things. For example, engineering and infrastructure data is in one format, environmental data is in another, and social and economic data in another. This makes creating systems that can appropriately manage and facilitate querying of each difficult.

The remainder of this dissertation will review the proposed methodological process of distilling these system requirements into technical solutions, developing a prototype system and a discussion of the results.

3.0 METHODOLOGY

3.1 INTRODUCTION

To reiterate, the fundamental aim of this study is to explore the nature and extent to which current spatial data infrastructures have been used for emergency management. Moreover, to contrast the effectiveness of these SDIs when inheriting the unique characteristics associated with a disaster situation. This study is being undertaken in response to the paucity of available technical research in this area. Despite the extensive existence of SDIs in the Western world, and their articulation and exploration by a wide variety of other disciplines, these areas remain fundamentally unaddressed in contemporary Emergency Management literature. It is submitted that by drawing on this and other research sources, the methodological approach used for this dissertation, provides an effective research base, which validates its analysis and increases its value. Furthermore, it is envisioned that this work will contribute to the growing international cross-disciplinary knowledge-base on 'SDIs for emergency management'.

The methodological approach employed in this research, supports and assists in the systematic progression of central themes which were identified at the outset, and which have provided a focus for the theoretical studies, and technical development. The outputs of this process were research findings which were constructed as both a challenge and an opportunity for disaster planning in the future. Furthermore, the nature of the outputs enabled the formulation of appropriate recommendations on proactive responses and reform measures that could be implemented by the in the course of future engagement.

3.2 METHODOLOGICAL AIMS

It is argued that all methodological processes must have stated aims to be effective. Accordingly, the central aims of this particular methodological process are:

- To provide a greater understanding of the relationship between the spatial data infrastructures and emergency management;
- To add to the existing body of academic knowledge on the nature and character of these areas;
- To provide a research base that will initiate and facilitate a more positive and proactive engagement between the Emergency Planning and SDIs in the future.

Furthermore, it can be observed that a robust and rationally based methodological framework and process will ensure that a relevant and appropriate research base informs this research work, thereby increasing its inherent value and ensuring that it meets the aforementioned aims.

3.3 METHODOLOGICAL APPROACH

A review of the relevant literature provided an important source of information to underpin this research. Relevant emergency management principles relating to the dissemination and management of data when a disaster occurs, were examined in order to extract background trends that could be used to construct a template for a prototype system.

3.3.1 Qualitative Research Methodologies

Punch (2005) asserts that "*research methods should be understood primarily as tools for answering research questions*". Two interlinked methodological approaches were used to underpin this research. The first of these is a desk-based analysis, a qualitative method of research which involved the critical evaluation of a range of International and European research, academic literature and other documentation material relevant to the research area. It has been argued that the aim of such an approach is to generate a comprehensive understanding of the research area so that the researcher becomes familiar with key concepts, issues and processes. In this regard, it is asserted by Punch (2005) that desk-based analysis provides a "*rich source of data for social research*". It is further submitted that this initial evaluation of secondary sources will inform subsequent enquiry and analysis.

To initiate the process of qualitative documentary analysis, I searched a number of key terms in the research database 'Google Scholar' and cross referenced what I perceived to be successful or relevant findings with the Trinity College Dublin (TCD) Library database, which allows student researchers to browse a wide range of peer reviewed academic journals. As stated in the previous section there is very little academic research done in this area that has a practical application, this made accessing relevant articles and research papers at the outset of the research process challenging. The key terms I used to search the aforementioned databases included:

- Spatial Database
- Spatial Database Management Systems
- Spatial Data Infrastructures
- Emergency Management
- Disaster Response
- Disaster Mitigation
- Spatial Data
- Accessing Data

It has previously been argued elsewhere, that for desk based analysis to be successful, it is imperative that the collected data must be properly read, understood, analysed and critically evaluated. In this regard, it was essential to extract a large amount of detailed information, in order to engender an adequate degree of familiarity with the key issues, actions, processes and problems which emerged. Specifically, this initial portion of the research process provided a general basis of understanding with regard to the nature, characteristic and factors underpinning the development of spatial data infrastructures.

3.3.2 Development of Proposal and Prototype Methodology

The second methodological approach used in this research was to test the proposal for the development of an improved SDI against a number of contextual scenarios. In the first instance this process will see the development of end-user requirements derived from National Health Organisations, International and Community based response efforts. These requirements are tested in terms of frequency they are raised, the spatial context in which they are raised and the tier within the organisation that it affects. Following this, the objective of the research is to create more suitable information frameworks for the storage, accessibility and development of spatial data infrastructures used in emergency management. A visual display of the methodology (broken down into the requirements stage and the prototype system stage) is displayed overleaf in figure 8.

Figure 8: Overview and relationships of tasks in methodology

The initial three tasks relate to systematic review of requirements

- Review mapping and spatial data requirements, interoperability and data acquisition
- Store, manage data and query data
- Facilitate analytical platform
- Ensure information delivery and accessibility

Subsequently, the project will develop a prototype system aimed at understanding some of the technical issues associated with developing such a holistic system. This will be broken into 3 parts.

- Set up system, framework and address data assets;
- Data Collection;
- Scenario Testing.

As mentioned in chapter 1, the target of this study was to develop a prototype spatial data infrastructure for use in emergency management (hereafter referred to as EM-SDI). With this approach it should be possible to visualize, edit and interact with relevant spatial data and models, particularly in the domain of emergency response. The construction work was started by getting familiar with the existing theory base. This literary review was carried out in order to gain insight into the given domain and to get some perspective on how the SDI should be implemented and which interaction possibilities should be included.

The implementation phase was divided into two sub-processes: the specification process and the implementation process. As mentioned in Chapter 1, the construction process was incremental in nature and therefore both sub-processes were carried out in parallel. As Järvinen & Järvinen (2000) have mentioned, the parallel completion of the specification process and the implementation process is often used in such situations where something completely new is being created. In these kinds of situations, it is judged that people in general find it difficult to imagine something that has never existed. Thus, it was considered beneficial to test the EM-SDI after each implemented prototype version and to update specifications accordingly. Every prototype also provided an opportunity to compare the current state to the target state, and to decide on the most necessary actions to be taken next.

In this chapter the specification and the implementation processes are described in more detail. The specification process is divided into three sub-tasks: defining the requirements, defining the components, and defining the architecture of the approach. The implementation process is examined by describing the software tools and technologies used in the implementation work, and comparing the first implemented prototype to the latest one. The comparison is carried out to illustrate the evolution of the application during the construction process. Finally, the most important interaction operations of the latest prototype version are explained in a detailed fashion.

3.4 REQUIREMENTS

There were some general requirements for the EM-SDI that were clear from the beginning of the construction work. For example, it was obvious from the start that the application needs to streamline interactivity for emergency management individuals. Users should be offered multiple methods of communicating with the visualized data. Another requirement was that EM-SDI should make better use of data indexing to minimise query duration and dependencies. EM-SDI should also take into consideration the characteristics of disaster scenarios and the unique environmental constraints therein.

There are many metrics against which to categorise SDIs in the incident management space, however the three most commonly referenced relate to the extent to which they can be used through the full lifecycle of civil protection, the extent to which it can be used across multiple tiers of management, and the extent to which the tool provides capability across multiple functions.

No official requirement specification documents have been written for EM-SDI, since the construction process was explorative by nature and it was clear that the requirements would evolve as the construction process progressed. However, some more specific requirements were defined and they are presented in Table 2.

Requirement	**Explanation**
R01	In the world of emergency management / resilience / disaster management the lifecycle is described generally as stages of preparation (planning, training, exercising), response (detection, initial response, considered response) recovery (reconstitution, reconstruction, review & mitigation) with a closed feedback loop into preparation. It is important that the EM-SDI can function effectively across the entire cycle.
R02	Tools spanning tiers of emergency management. Although an SDI typically focuses on the usefulness of its tools at the strategic level, in order for it to deliver the necessary situational awareness to support informed decision making it is vital that the toolset either permeates to lower tiers of management or integrates with systems that already exist at lower tiers of management.
R03	The spatial data stored on the system must be highly interoperable.

R04	EM-SDI offers multiple operations for editing the visualization. Users should be able to at least add, delete, rotate and move entities. Users are able not only to edit the visualization, but to directly manipulate the ontological data through visualization.
R05	EM-SDI is able to present contextual data and spatial relationships effectively
R06	The ability to manage information, which can be done in several different ways. Log of events and actions taken may be recorded automatically in relation to time and date, making it easier to access data at a later stage.
R07	The ability to provide portable resources such as portable laptops, or have access points in the mobilising vehicle, which allows command units to access information from the 'at scene'.
R08	EM-SDI offers extensive and effective query possibilities. Users should be able to execute queries both graphically and textually.
R09	The ability to operate the software and access data. It is convenient to ensure that all trained users are able to use the software without any restrictions. However this means the data and information is available to everyone and anyone and this can be seen as being irresponsible. Assigning usernames and possible passwords assures safety and privacy of low and high priority information.
R10	EM-SDI should be easy to use. Usability issues are taken into consideration in the design process of the user interface.
R11	The system must be web-based and accessible on multiple forms of desktop and portable devices
R12	Given the nature of spatial data (large size) it will be important for prospective systems to find a way to segment data based on a users tailored requirements

Table 2: Table of requirements for EM-SDI

The first two requirements (R01-R-2) are strategic in nature and deal with overall fit of a system within existing policy and procedural frameworks. This manifests in system in terms of functionality. The EM-SDI must cater to host of disaster and modelling types and to wide variety of technical and non-technical users.

Requirement 3 and 4 (R03-R04) refer to certain technical features not classically embedded in SDIs. Amongst other functions an SDI must cater for powerful predictive modelling, enabling organisations to classify categorical variables, and to estimate continuous variables using mathematical algorithms.

The next requirement (R08) was to ensure the EM-SDI is flexible enough to handle the wide-ranging queries it must be able to perform. It is often a good idea to offer multiple ways to perform queries. Thus, it was decided that EM-SDI should offer two distinct options for query construction, a graphical query and a textual query. With the graphical or map based query option it is judged that non-technical or inexpert users should also be able to input requests without having any specific background or familiarity of the ontology query languages. With the textual query option, advanced users should be able to define their own query statements without any constraints.

Also, requirements R09 and R10 are closely attached to interaction issues. Requirement R10 was defined in order to ensure that usability issues are taken into consideration during the construction process. According to Nielsen (1993), usability should be classified with respect to, learnability, efficiency, memorability, and operating without errors.

The final two requirements relate to the accessibility of the data (R11 and R12). In the past SDI system were used primarily by data analysts. As such, they had very little need to operate outside of an office environment equipped with powerful desktop computers and high data transfer rates. New SDIs system built for emergency management must consider that a minority of very important users of the system will not have a powerful computer (perhaps no computer at all, maybe a laptop or mobile device) nor will they have high speed internet capable of super fast data transfer. Thus, a rethink is required on the mechanism by which you can get succinct, timely and accurate data to these users.

3.4.1 Scenario Definition

The scenario definition will be discussed in more detail in the evaluation section of the thesis, but generally, relates to testing the a developed SDI within the context of a set of real scenarios. The purpose of which is to uncover expected issues which may occur as users attempt to use an SDI during an actual disaster. A number of common disaster scenarios are tested to validate the capacity of standard SDIs to accommodate all types of interrogation and efficient knowledge dissemination to appropriate tiers of users.

By looking at the types of scenarios that must be cater for we can derive a prototype that can support all aspects of data management for emergency management in these scenarios which could create a template for future considerations.

The thesis will focus on 3 scenarios

- Scenario 1: Cross-border Chemical Explosion
- Scenario 2: Regional & Interregional Mass Flooding
- Scenario 3: Large-Scale Biological Exposure

The 3 scenarios (and sub-scenarios such as evacuations of impacted populations and water contamination) will allow a comprehensive assessment of the SDI functionality and workings, through all 3 phase of incident management. The scenarios will identify resource constraints and capability gaps in current end user plan and conclusion can be drawn on how this thesis will address these.

3.5 EM-SDI ARCHITECTURE

The application draws on Sinatra as the front end web framework utilising Ruby and HTML internally[3]. The map is designed using OpenLayers[4], which sends requests from the front end of the application based on either keywords or the geographic boundary selected, to the application server. The application server hosts Geoserver[5] and Geonetwork[6] tools. All requests for data are sent to these servers which store the majority of the spatial data (including metadata). The tool stores descriptions of the various layers that are required to project on the map in the front end, and resource link containing the workspace and layer name that are already present on the Geoserver.

After creating the metadata we need to publish the data so that it can be viewed in the front end. When the user publishes the metadata, the Geoserver layers actually get published to the user and the user can then view those layers. The application interacts with the Geonetwork server by sending a http request and gets the response in XML and captures the information from it.

[3] Sinatra is a free/open source software web application library and domain-specific language written in Ruby.
[4] OpenLayers is an open source JavaScript library for displaying map data in web browsers. It provides an API for building rich web-based geographic applications similar to Google Maps and Bing Maps.
[5] GeoServer is an open source server for sharing geospatial data which is designed for interoperability (publishes data from any major spatial data source using open standards).
[6] Geonetwork is a spatial metadata catalogue which contains in built map viewer control.

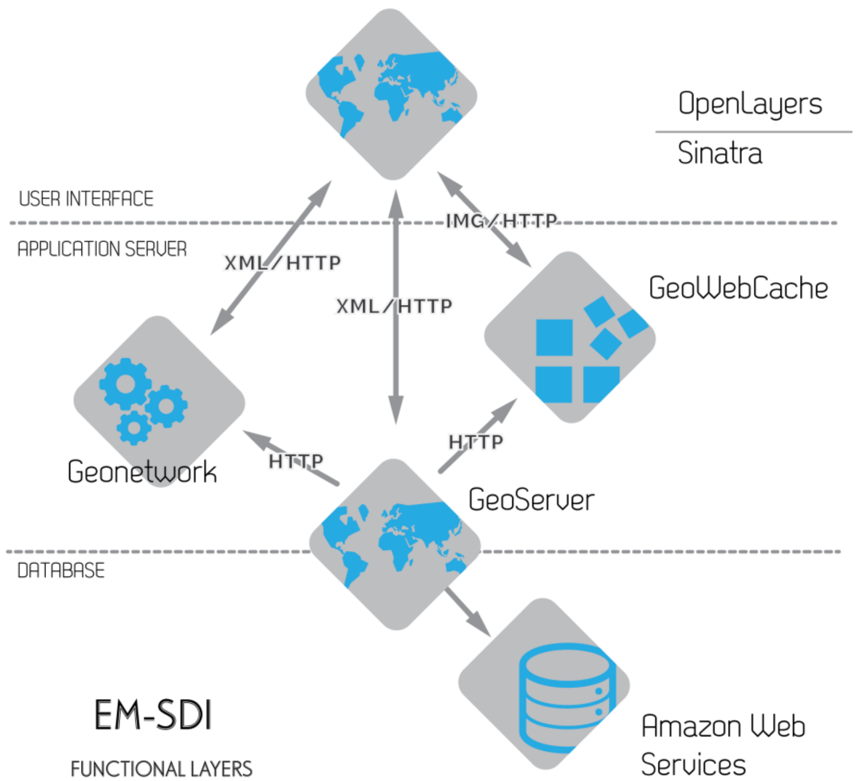

Figure 9 EM-SDI Functional Layers

The study has selected a number of open-source technologies to carry out a number of functional roles:

- **Storage:** The EM-SDI primarily utilises Geoservers' internal GIS file format system. Geoserver has the capability to read and write data from GIS file formats consistently and very easily. Additionally, Amazon Web Services (AWS) databases have been used to store larger or static raster data (e.g. DEMs).
- **Application Server:** The application server is used to access and render datasets gathered for the EM-SDI. The project uses Apache Tomcat hosting GeoServer map/feature server and Geonetwork /spatial catalogue Server.
- **Application Cache:** Performance depends on the caching of intermediate results, such as map files. Geoserver uses the GeoWebCache tile cache which acts as the protocol gateway.
- **User Interface framework:** The user interface uses Sinatra framework for building the web application.

- **User Interface Map Component:** Geospatial applications require a map component capable of processing spatial typologies and map layers. This application uses OpenLayers and a javascript library to create UI.

The database answers general queries as well as the standard attribute queries. The geoserver map/feature server can provide standardised web access to underlying GIS data sources or GIS file formats. The GeoWebCache tile server stores map tiles and can selectively cache and serve map tiles using standard web protocols for the requests and responses. Sinatra framework and Openlayers facilitate the user interface modules and also specific bindings for the geospatial data types.

Data quality control: To ensure the outputs of the study are delivered to the highest quality, a standardised methodological framework will be applied to all data sourced or created. This strategy will ensure that sufficient checks occur throughout the lifecycle of all information used in the study. The framework works on two levels (see Figure 10):

1. At the research level - Accuracy and reliability of original information sourced and;
2. At the database level - Consistency, integrity and timeliness and validity of the data.

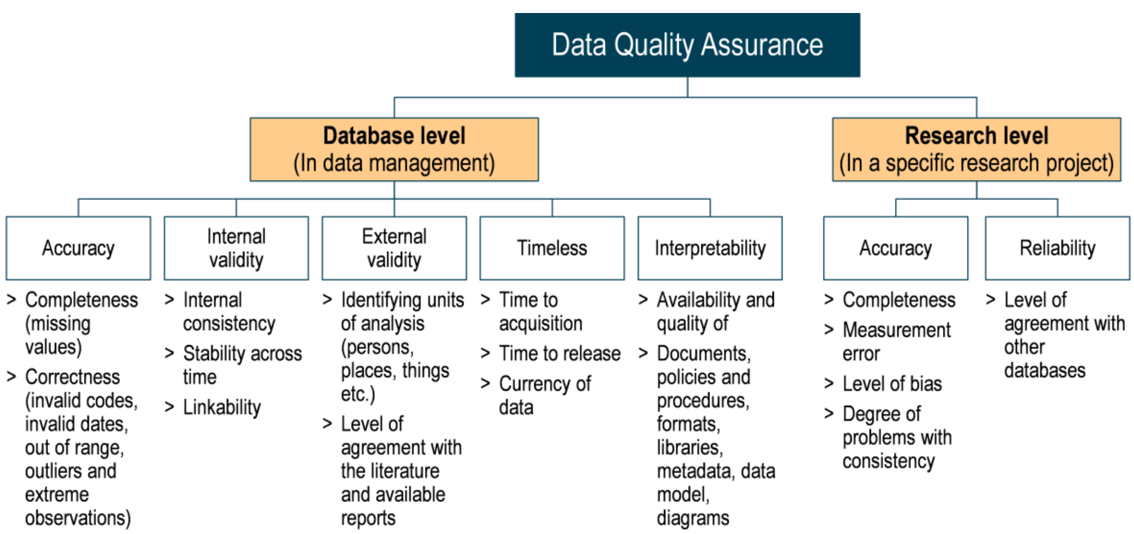

Figure 10: Data quality assurance system

Similarly, standards will be established from the outset with respect to metadata. An INSPIRE Directive Compliant template will ensure that all data used in the project will be transparent and interoperable across reader and visualisation platforms.

The EM-SDI primarily utilises Geoservers' internal GIS file format system. Geoserver has the capability to read and write data from GIS file formats consistently and very easily. While the database offers the strongest combination of data integrity and support for write operations, the architecture is restricted in how it visualises certain information format types. For example:

- Geoserver can read from or write to GIS files:
    - ESRI Shapefiles;
    - Image File Formats(GeoTIFF, ECW, JPEG2000, JPG/PNG/GIF).
- Geoserver can read data directly from the standard internet service:
    - OGC WebMapService for access to imagery and rendered maps;
    - OGC WebMapFeature for access to vector features.

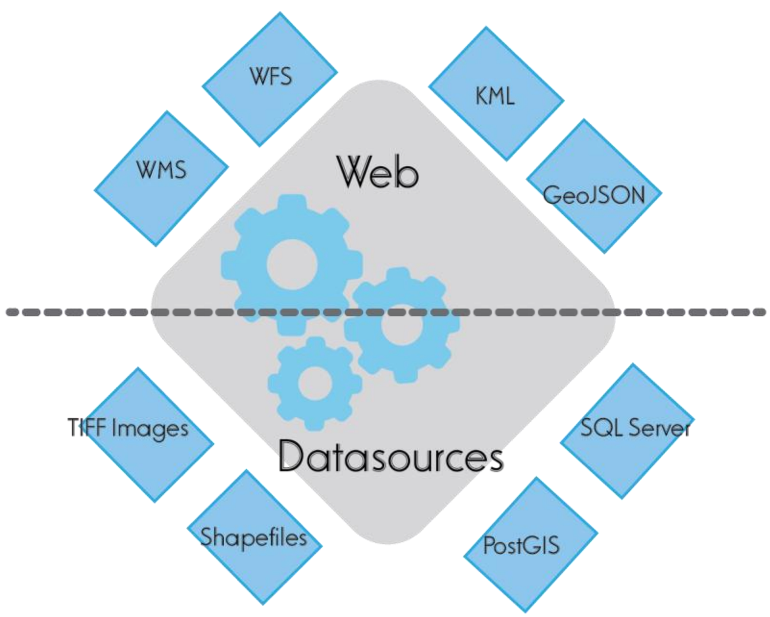

Figure 11: Compatible Spatial File Formats

Additionally, Amazon Web Services (AWS) databases have been incorporated into the project to store larger or static raster data (e.g. Digital Elevation Models). This information is not compatible with GeoServer and must be stored in a more linear fashion within a non-spatial database.

Application Server

The application server layer is responsible for meditating between the data layer and the user interface layer (UI). It acts as a protocol gateway, turning standard web requests from the UI into the bespoke messages required to communicate with databases or to extract vector geometries from the geospatial files. The EM-SDI hosts Geoserver and Geonetwork on Apache Tomcat[7].

Layers in the application are stored on the Geoserver in shapefile or tiff file format and are projected on the map depending on the location or search criteria. The description and other details of the given layer are gathered from the Geonetwork. The user sends a http request to the Geonetwork and the response is in the form of XML format which is read by the application. The information is then presented in HTML form to the user. The links are created in the application which points to the Geoserver for accessing the raster data (like kml, jpeg etc) and vector data (shapefile, etc).

Geoserver makes use of the web services like WMS and WFS for rendering the information from their server to the user. Geoserver makes use of the WFS (getting vector data) that allows uniform rendering access to the features stored on the server and WMS when the user wants to perform certain actions such as producing maps and simple querying for the data (getting raster data).

[7] Apache Tomcat is an open source web server and servlet container implements the Java Servlet and the JavaServer Pages (JSP) specifications from Oracle, and provides a "pure Java" HTTP web server environment for Java code to run in.

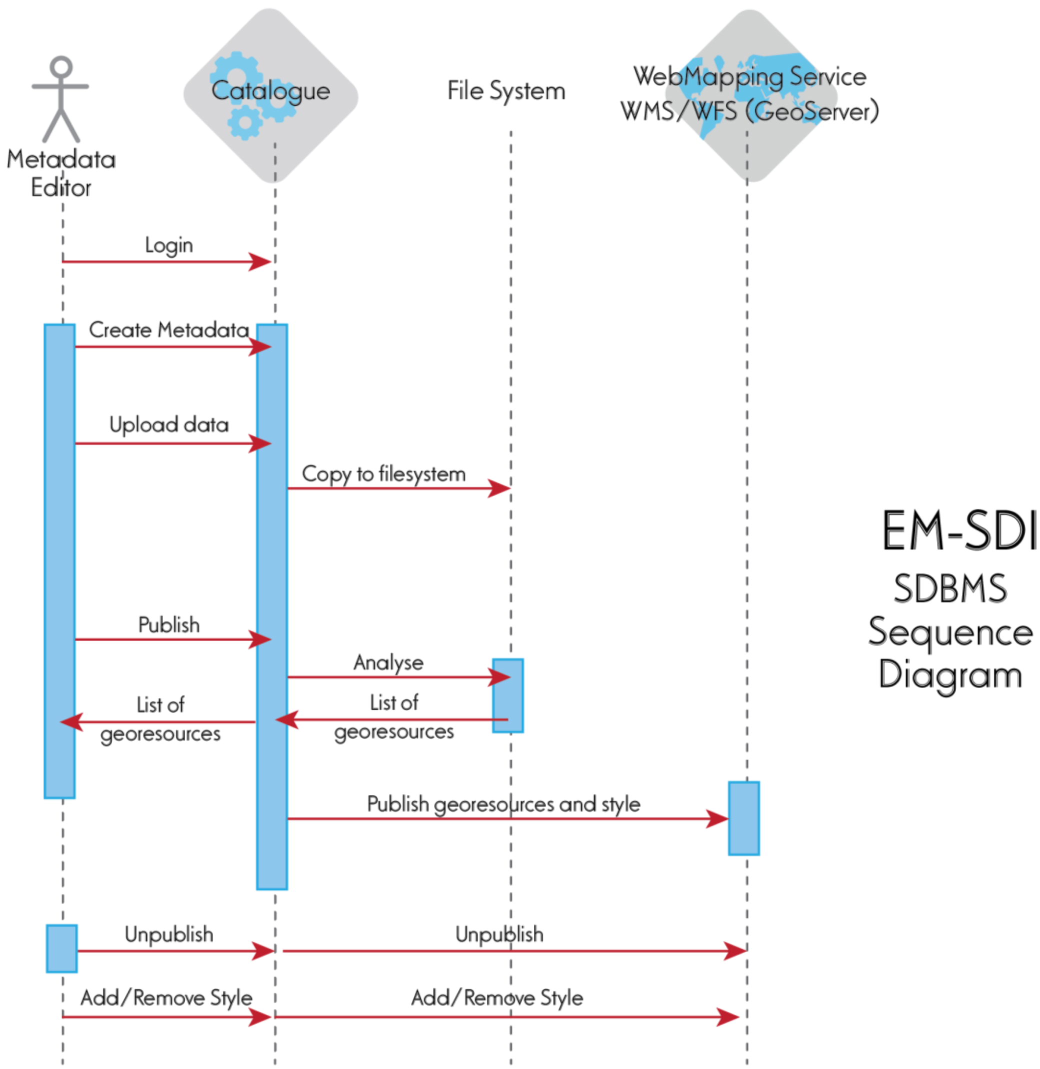

Figure 12: Sequence Diagram

Application Cache

Geowebcache is a protocol gateway. It operates between the tiled mapping components and the rendering engine in the Geoserver. Tiled map components invariably have a significant number of the parallel requests which also have the same spatial extent which make them ideal for caching geospatial data. Geowebcache takes the requests request for tiles, performs a check on its internal cache to see if a copy of the request already exists, and if it doesn't, it transmits the response to the Geoserver using WMS requests.

User Interface framework
The front end user interface layout is designed using Sinatra web framework and its Ruby Micro framework containing html tags and has erb extensions (Ruby). The application builds a map component using Openlayers.

3.6 METHODOLOGICAL DIFFICULTIES AND ISSUES

It can be observed that any methodological research process is subject to limitations and potential problems. Furthermore, it is submitted that acknowledging and addressing these issues can strengthen rather than weaken the methodological framework, by demonstrating the honesty, transparency and integrity of the research process. On this basis, the issues and constraints affecting the methodological process informing this work will now be outlined.

The primary limitations affecting the nature and scope of this research were resource-based, and included limitations on time and finance. As this research is being independently carried out, and therefore not funded by any third party, it has been subject to very limited financial resources. The project has where possible incorporated as much open-source components as possible but having to build this system from the ground up created create certain inefficiencies that could have been avoided if finance was not an issue.

Similarly, due to temporal limitations, it did not prove possible to devote enough pure man hours to the development potion of the application taking into consideration the research component, write up etc. While I recognise that it would have been advantageous to present solutions to as many of the requirements as possible, the relative lack of resources to complete these bespoke components ensured that this was not possible. Instead certain ameliorations are presented by testing the requirement against each of the scenarios.

However, despite these financial and temporal resource limitations, it is contended that the methodological approaches used in the course of this research process, are adequate and provide a sufficiently appropriate and robust research base for the purposes of this dissertation.

Another significant issue often highlighted as affecting methodological frameworks, is professional or researcher bias. Bias is argued to affect the objectivity of professional research, when the methodological process adopted and the findings generated are in some way purposely engineered to support a pre-determined agenda or outcome. This is certainly an issue that I am consciously aware of at all times, and try to ensure that it does not impact on these results. However, it is unrealistic to expect research to be value neutral, and it is submitted that all forms of methodological research may be subject to some sort of professional bias as they feature human involvement. In summary, the threat of professional bias has informed the research process from the very beginning and a conscious effort has been made through the progression of the study to avoid such bias and to engage objectively with the research, in order to generate authentic results.

3.7 CONCLUSION

The stated aims of the analytical framework and empirical research process underpinning this dissertation are to generate an understanding of the potential limitations of current SDI which are used in Emergency Management and Disaster Relief situations'. It is argued that the methodological procedure of research design, requirements and prototype development undertaken, which involved documentary analysis from conventional academic literature, European research initiatives and commercial software's currently acting in that capacity, was sufficient to create a comprehensive and robust research base that provided internal and external validation for this dissertation research and its findings.

4.0 EVALUATION

4.1 INTRODUCTION

This section discusses the implemented methodology. Firstly, the prototype SDI is explained in terms of functionality, and the process through which a user accesses data. Following this, the study aims to evaluate the positive and negative outcomes in attempting to address the requirements set out in the methodology, in particular when they placed against the realities of a real world scenario. Finally, conclusions are drawn on the effectiveness of the prototype, as well as the general compatibility of emergency management goals against the inherent characteristics of SDIs.

4.2 PROTOTYPE SDI

The EM-SDI, a screenshot of which is shown below in Figure 13, provides access to the EM-SDI distributed metadata, data, and maps through a unique graphical interface. The initial interface allows the user to select the geographic extents or reach of the information required and/or keywords or sentences that describe the information source themselves (e.g. Flood, Digital Elevation Models {DEM} etc.). This search process ensures rapid partition of suitable data sources across a European scale into useful, relevant and timely data and results.

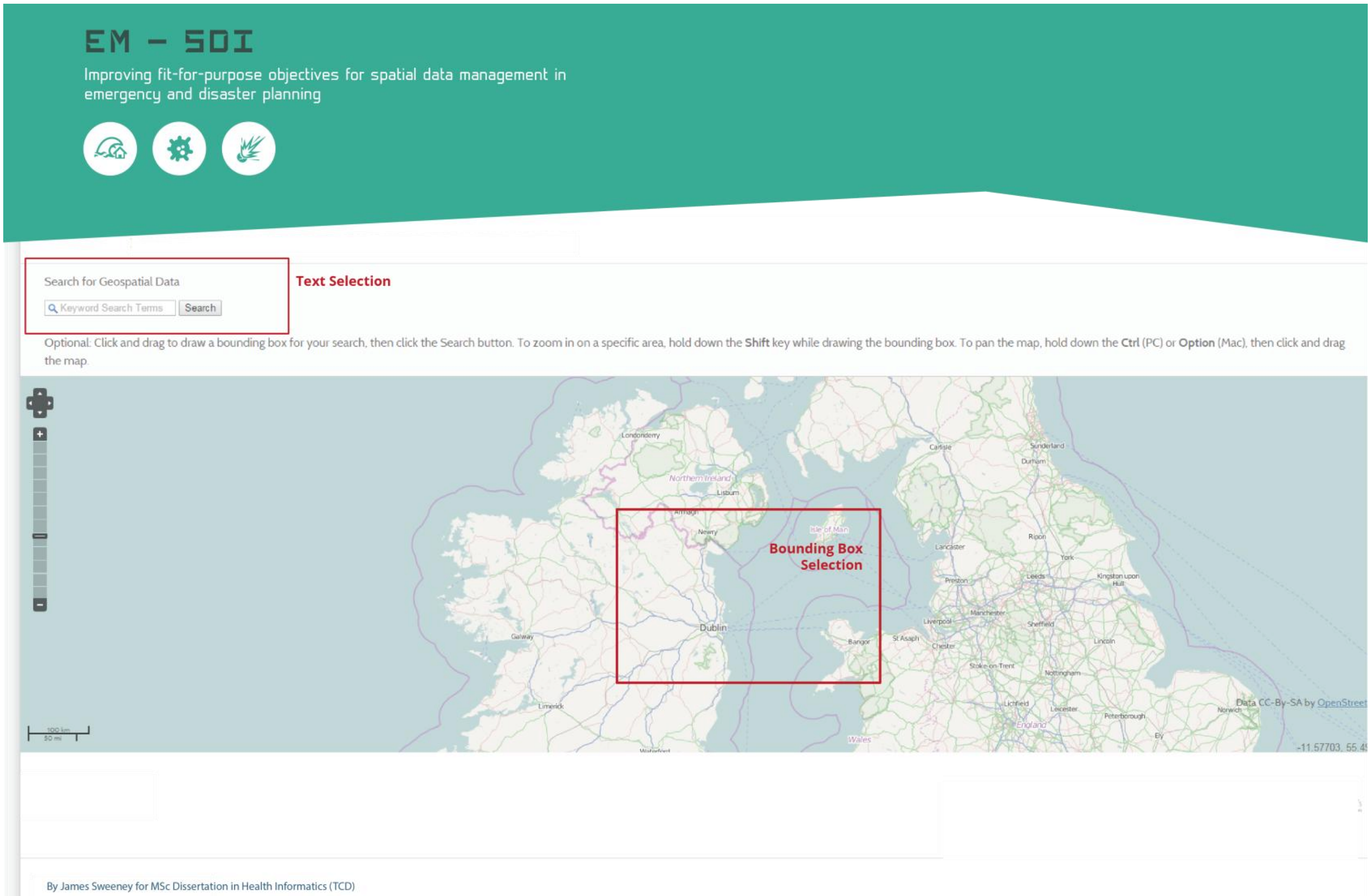

Figure 13: Screenshot of the EM-SDI

By selecting via keyword or geographic reach, the user will be directed to the sources of information in the database that correspond only to this definition and a list of datasets matching the selected themes will be displayed (Figure 14). The user then selects a title which best describes users need(s).

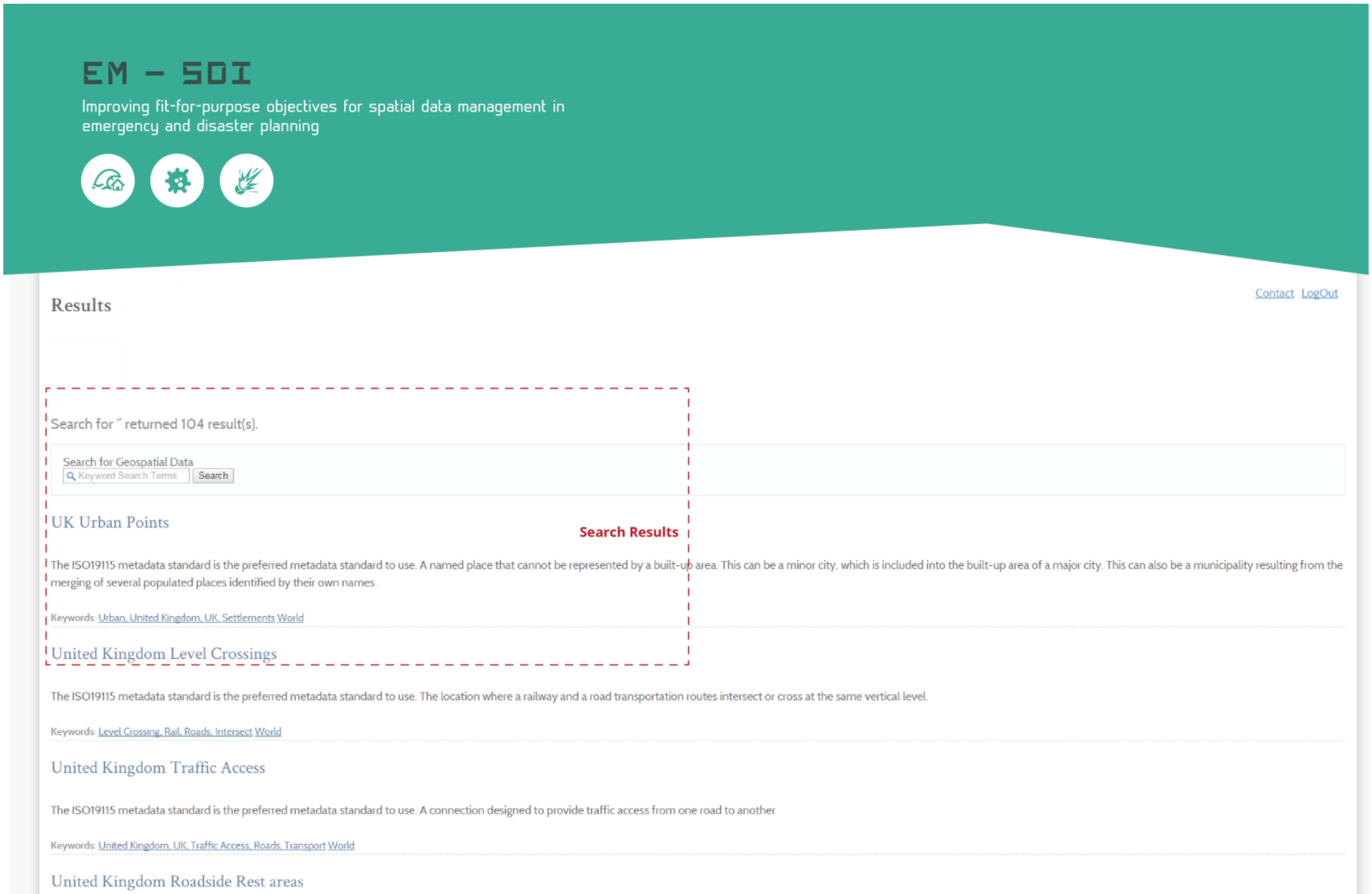

Figure 14: Screenshot of the EM-SDI - Results Page

Once the user selects the final dataset one is then brought to the 'download page' for that entry (Figure 15). The page provides the context in the form of the 'map area' and the first column on the left (**Title:** 1. Context and Metadata Area). This provides information about what the dataset is and how it was collected.

If the selected dataset is available for download, the user can select from the panel to the right (**Title:** 2. Download for individual layers) which format he/she would require to visualise or do post analysis of that data source. Certain larger datasets (e.g. National DEMs) cannot be viewed within map viewer. However the link to the file alongside the metadata will ensure that the user is directed to the appropriate data source.

The user can manage the data layers using the "Layers" tab in the right hand corner under the map box (**Title:** 3. Dropdown for map layers).

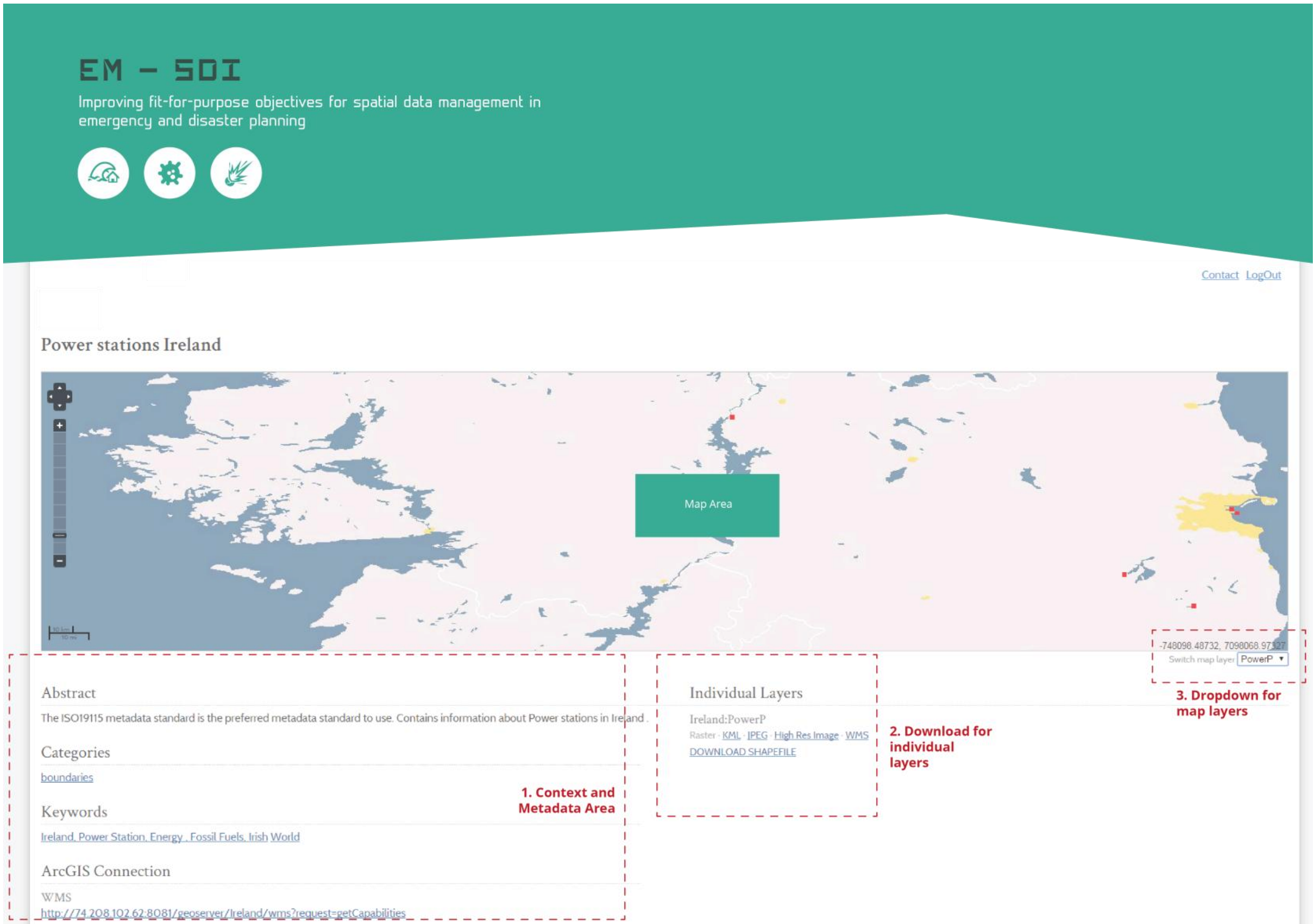

Figure 15: Screenshot of the EM-SDI - Individual Datasource Page

4.2.1 Data and Metadata

For the purposes of this dissertation, the EM-SDI made use of available open data sources. Data collection was considered on two spatial scales; the Pan-European and the local level. A significant amount of context data was derived at a Pan-European scale. This information will be useful for analytics at a regional or national scale. Similarly, a more granular database of information was developed at a small area level. It was considered that for the EM-SDI scenarios more granular data on population, socio-economic, housing, hospital/GPs information and so on would be sourced at an XY scale (or as close to this as possible). This will ensure a richer, more defined impact analysis for the case study areas is possible.

The data gathered was developed thematically, as well as spatially. All data was classified under the INSPIRE themes to assist the end-users in locating appropriate datasets. The EM-SDI platform has connectors to data sources that will be automatically processed, pre-analysed and geo-mapped to present a useful and understandable situational awareness picture to the user. The table below provides an indicative view of the types of more granular data retrieved for the case study scenarios:

Theme: People and Place	
Dataset	**Description**
Fire Stations	A geographic representation of the location of fire stations including attribute information such as address, opening hours etc).
Power Lines and Power Stations	A spatial datasets illustrating the location of the primary power lines in Belfast and the interdependencies of these in other areas of the study area.
Police Stations	Location of all police stations in the study area.
Population (and derivatives)	Census information at a small area level (50-150 households) for populations in an area, density, characteristics of people.
Socio-Economic and Area Profiles	Spatial layer by geographic area showing socio-economic and demographic trends in the study area.
Places of Interest and Landmark locations	A spatial layer representing landmark locations in the study area.
National Park & Nature Reserve	A spatial layer representing national parks in the study area.
Schools	Location of all schools in the study area (includes primary/secondary).
Educational Attainment	Spatial layer by geographic area showing educational attainment in the study area.
Theme: Transport	
Road Networks	A spatial layer representing the principal road networks within the study area.
Airports and Runways	A spatial layer representing the location of airports in the study area.
Rail Lines	The linear network of rail lines in the study area.
Train Stations	The location of the main train stations in the study area.
Bus Stations	The location of the main bus stations in the study area.
Theme: Housing and Accommodation	
Housing	Census information at a small area level (50-150 households) on the number of houses, apartments etc.
Housing Tenure	Census information at a small area level (50-150 households) on

	the housing tenure.
Housing Occupancy	Census information at a small area level (50-150 households) on the housing occupancy, number of rooms etc.
Theme: Health and Needs	
Hospitals	Location of all hospitals in the study area
General Practitioner Surgeries	Location of all Doctor surgeries in the study area
Theme: Environmental	
DEM	Digital Elevation models for flood modelling and terrain analysis for the study area at a 30m resolution.
Contours	A spatial datasets of geographical elevation contour lines at a 10m definition.
Rivers & Water Features	A spatial layer representing all the lakes, rivers and other water features in the study area.

Table 3: An example table of the type of more granular data retrieved

4.2.2 System Functionality

The EM-SDI has been designed to act as a resource for activities relating to an emergency response effort. The system would act as an aid in spatial modelling and mapping to capture detailed perspectives on a range of scenarios from across Europe. Specifically, the web-based system has been developed with following features:

- A mapping interface with the common map controls (zoom, pan, feature information, navigation to an area of interest, etc.);
- Data collected is fully INSPIRE compliant;
- Simple and advanced spatial data search capability;
- Centralised data storage. Rather than linking data sources across the web from a range of sources, the EM-SDI collects a version of each dataset and hosts it internally ensuring no issues arise with respect to permalink changes, or inefficiencies occurring from calling information from other servers;
- Immediate and search access to local and distributed geospatial catalogues;
- Up/downloading of data, graphics, documents, pdf files and any other content files;
- An interactive web map viewer to combine web map services from distributed servers around the world;
- Online editing of metadata with template system;

- Data which has been collected (where appropriate) and has undergone data transformations and translations to ensure end users are afforded data sources in formats conducive to further analysis or visualisation (e.g. Spatial Analysts require spatial formats [.shp, .tab], while engineers require CAD [.dwf] files); and,
- Capacity and appropriate pathways to reintegrate and improve static data sources within the system. Equally, the facility to accommodate models and outputs derived from other emergency management related activities (e.g. Plume Model Scenarios, Flood Impact Models).

It would be intended that the EMI SDI be used as a forecasting tool, but also during an incident, and as a learning tool post incident. The exercise of comparing the strengths and weaknesses of utilising SDI in each stage will be assessed across these phases of disaster management and for the possible types of end user.

4.3 SCENARIO DEVELOPMENT

The section will provide an overview of types of disasters which will be covered in the study. It is judged the following disasters broadly represent the spectrum of disaster types that exist in the world, and thus, a good framework to carry out the requirements assessment.

In order to most appropriate contextualise each scenario, the study will use end-users stories across the timeline of the disaster to assess the impacts. The scenarios will broadly relate to spectrum of a disaster and its response efforts

The assessment will aim to test the use of the EM-SDI tool against the lessons learned across the 3 scenarios. The baseline of events and the before and after analysis will enable a cross comparison to the 3 incidents to provide deeper understanding the preparedness of the different groups and the different decision-making during the 3 separate responses.

4.3.1 Scenario 1: Chemical Release

There is a large scale chemical explosion in an illegal drug lab located in a residential area, and there are a range of responding agencies.

There are three stages to the unfolding scenario;

- Unexplained and widespread incidents in the drug user community.
- Explosion and Fire at an industrial scale drug lab leading to a significant toxic plume.
- Run-off into water-table compromising the potable water supply, restoration and clean-up.

Scenario Timeline

Week 1 - 2	1st few cases of contaminated drugs. Then widespread cases of contaminated drugs.
Week 3	Intelligence begins to point to a single source in Ireland. Intelligence identifies an industrial scale drug lab at a particular location near a residential area
Week 4	There is raid on the illicit drug lab that goes badly wrong and results in a fire explosion and toxic plume. This fire is occurring is in a built up area and was also storing significant amounts of other as yet unidentified chemicals used in various criminal activities. A toxic plume drifts towards major centre of population. Fire is uncontrolled for some time and contaminated firewater enters the river
Week 4	Incident is brought under control after two days
Week 5>	Emergency Departments are seeing a big increase in presentations related to the contaminated drugs in free circulation.
Week 5>	ICU is under particular pressure as a result of the effects and the longer than average stays. Number of ambulance calls has risen by 11% almost entirely related to fears arising from the contaminated drugs

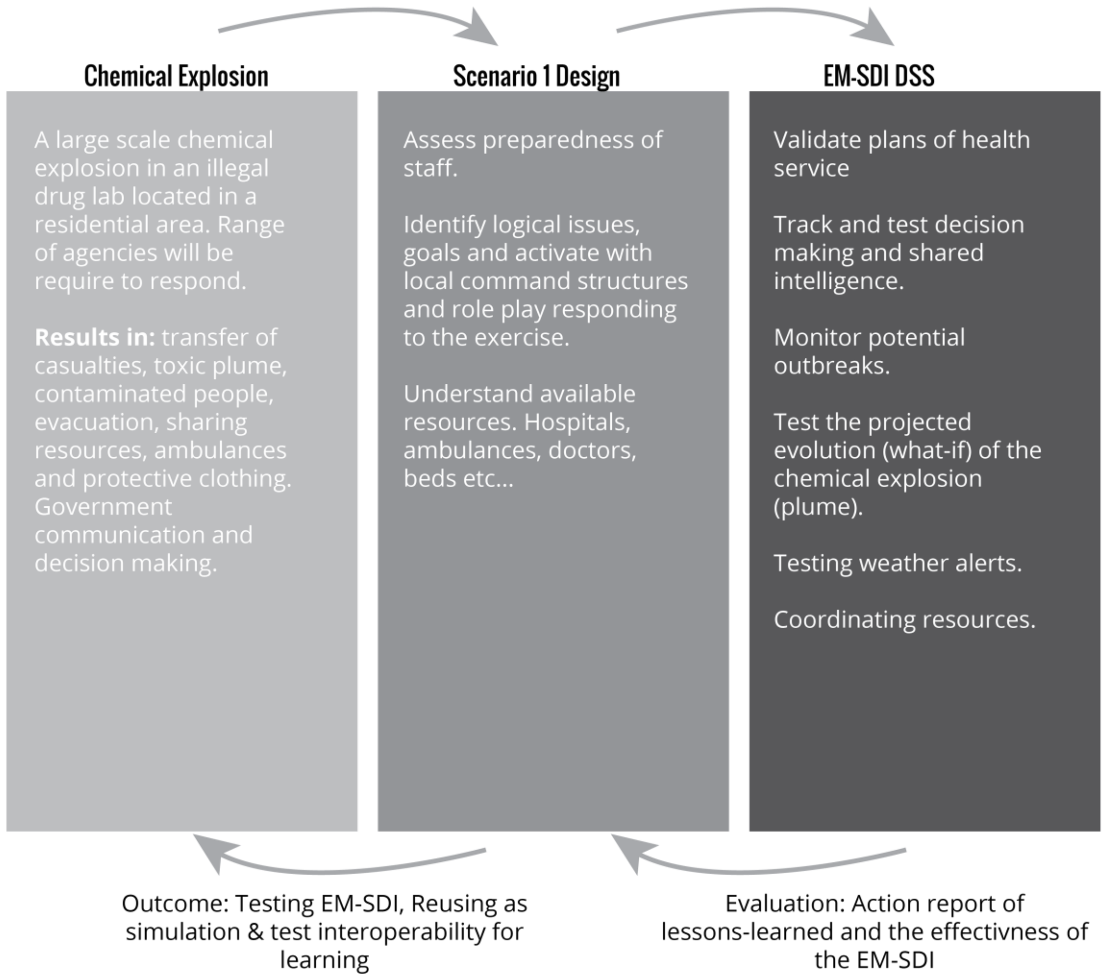

Figure 16: Scenario 1 Chemical Explosion

This results in a number of intended and knock-on effects which must be understood and handled appropriately. More specifically, it results in: transfer of casualties, toxic plume, contaminated people, evacuation, sharing resources, ambulances and protective clothing. Government communication and the need for effective decision making.

4.3.1.1 Implementation of Scenario 1

Within this timeframe of activity the chemical contamination has spread far beyond those perhaps taking drugs to the wider local population. The toxic plume/cloud has spread harmful chemicals which is now presenting in the number of people in need of health services.

In this case, the EM-SDI will be used as a decision support tool, post incident. It will facilitate incident commanders and their team to analyse the current impacts of the disaster and model for future impacts. A plume model is typically done to determine the extent of a toxic cloud. A plume takes into account information on the contaminants themselves, alongside environmental characteristics like, wind speed and direction, typography of the land, population affected.

Equally, there is more of a strain on the health services with the number of new cases presenting as a result of the toxic plume. Thus, emergency mangers need to allocate, reallocate and distribute additional medical services to all those in need. The EM-SDI would contain information about hospitals and hospital resources (hospital beds, ambulance, doctors etc). This will better facilitate awareness about the resources or perhaps lack of resources available to handle the disaster.

If an evacuation is called it is crucial that all tiers within the response efforts understand who is living in the contaminated areas. The EM-SDI holds information on the populations of the area, those perhaps more vulnerable/dependant (like disabled, older or younger cohorts of the population) and where the live. This enables responding efforts to have a kind of checklist in terms of if everyone is present, who is missing, and where are they likely to be.

Facilitate a better awareness of the situation on the ground, and thus can be used by government to incisively act on information, as opposed to dogmatically following protocol when this type of disaster happens.

4.3.2 Scenario 2: Mass Flooding

Extreme Rainfall experienced in several locations during the day. This has caused a rising tides and tide-locking in estuaries. There is widespread surface water flooding of rural areas, town and urban locations.

There are three stages to the unfolding scenario;

- National weather organizations forecast the storm via satellite imagery. They don't know the extent but they issue a weather warning.
- Storm hits and its worse than had been expected, causing widespread damage to infrastructure and hinder mobility of populations.
- The storm has passed and responding organisations are at full alert post-incident aiming to better disseminate health services, provide clear channels for communication and reopening infrastructure.

Scenario Timeline

Day 1 Cause for Concern	A severe weather system associated with high winds and significant rainfall is detected over the Atlantic Ocean. This, coupled with the fact that there are rising tides ahead, the ground is saturated, rivers are flowing at elevated levels, lying snow is beginning to melt in some regions, and reservoirs are 80-100% full, raises cause for concern.
Day 2 - Deepening low pressure system	The weather front begins to cross over England and Wales causing substantial rainfall in various locations which results in localised flooding in several locations. Flood warnings are issued as it is predicted that the severe weather conditions will potentially impact the whole region.
Day 3 - Extreme rainfall and further flooding	Extreme rainfall is experienced throughout the day, as well as rising tides and tide-locking in estuaries and tidal reaches. Surface water flooding occurs in rural areas, towns and urban locations across Wales and 3 English regions which result in significant property damage and the loss of essential services and infrastructure.
Day 4 - Landfall of the storm	Landfall of the storm travelling from the Atlantic Ocean occurs across central England causing high winds and persistent, heavy, and widespread rainfall. As a result, there has been flooding of rural villages and urban conurbations around main rivers, as well as significant transport and electricity network disruption causing many communities to be cut off. There is widespread public alarm & panic.
Day 5 - Stormy weather ongoing	Storm force south westerly winds in the North Sea create significant surge and wave action battering the east coast and the overtopping and failure of sea defences in several locations lead to severe flooding in coastal zones. There is further damage to property and local transport services caused by the flooding. There are several reports of missing persons.

	Meanwhile, snow melting on high ground worsens the ongoing runoff in valley regions of Wales and the North West. There is an uncontrolled release of water from 2 reservoirs (one partial collapse) resulting in significant inundation. Large numbers of casualties are reported following a number of collapsed buildings. At least two of the main hospitals in the valleys region of Wales are largely inaccessible due to road closures arising from extensive flooding.
Day 6 - Stormy conditions continue	Overtopping and failure of sea defences in several locations leading to further severe flooding in coastal zones. Significant property flooding; loss of local transport services.
Day 7 - Storm begins to pass	Finally the storm begins to break and pass in an easterly direction and a period of dryer and calmer conditions with scattered showers, mist and fog follows. Flood waters are beginning to recede and recovery efforts have begun. The full extent of damage is apparent. Displaced persons is an immediate concern. Public health issues remain a serious concern. Efforts are ongoing to restore/repair essential infrastructure.

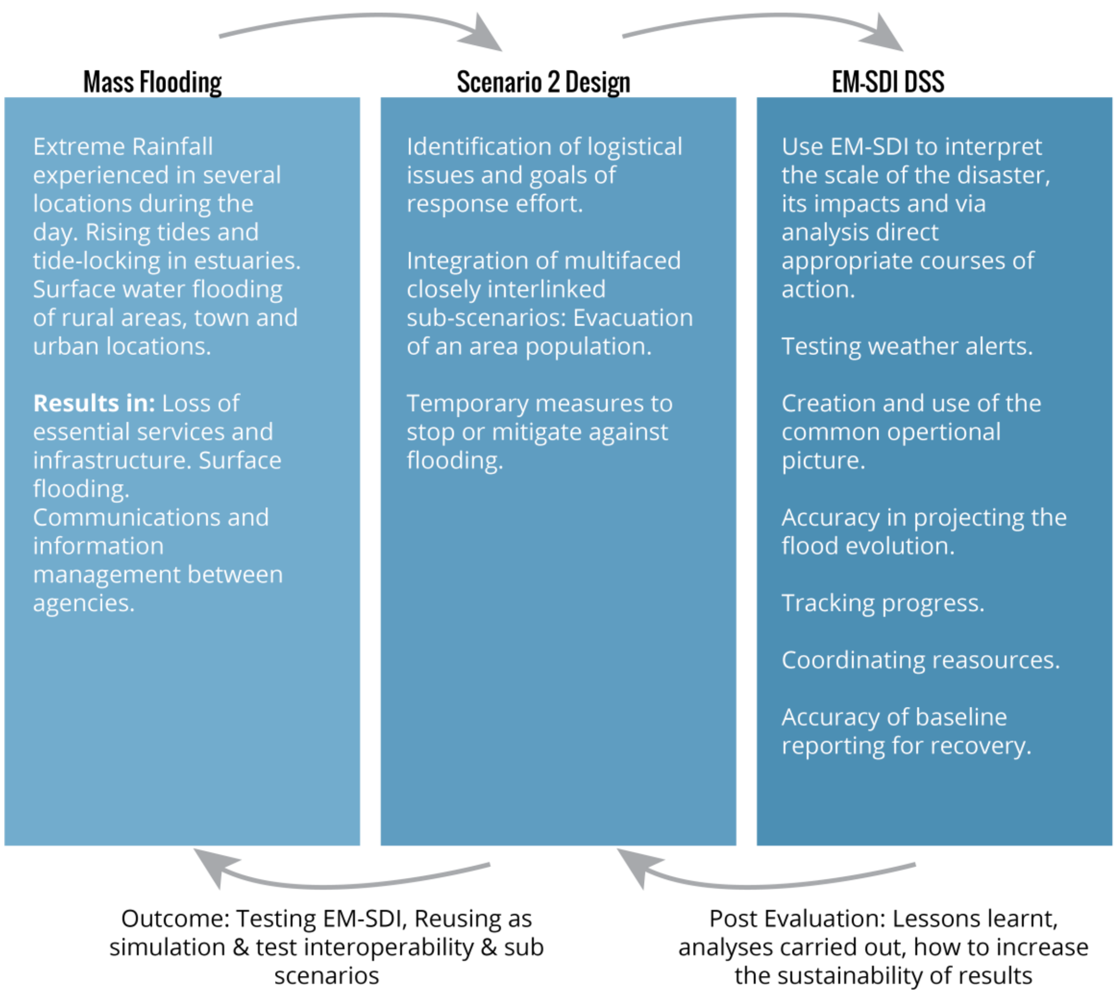

Figure 17: Scenario 2 Mass Flooding

This results in a number of expected negative impacts. Specifically, there is a loss of essential services and infrastructure. Roads and transportation infrastructure becomes unusable. Weather conditions worsen with surface flooding stop mobility for isolated individuals. There is extensive damage to properties including hospitals, schools and retirement homes. Many towns and villages are inaccessible and there are a number of reports of missing persons.

4.3.2.1 Implementation of Scenario 2

The EM-SDI would be used to determine the scale of the disaster, its impacts, and via analysis an appropriate course of action to take in a mass flooding event. By testing weather alerts, flood modelling, baseline analysis the EM-SDI can assist in provide actionable data to the main stakeholders involved. Equally, data on infrastructure and populations (particularly vulnerable cohorts of society) is registered with the database and can be called to perform impact analysis or coordinate evacuation or other response efforts.

The EM-SDI would be able to accurately project the flood evolution and could be used pre incident as a forewarning tool, during as an as is picture, and post as a learning to for future disasters. Particularly, real-time/time series modelling on current or historic trends will help to develop a picture of how the landscape has changed from the past to the present. Equally what factors could have led to this position. Predictive analysis (What-if modelling) on data characteristics will facilitate a better understanding of a range of attribute information about a flood scenario. Additionally, prescriptive modelling, simulation and optimisation can be used to support decision making by enabling the selection of the correct value of a variable based on a set of constraints for deterministic processes, and by modelling outcomes for stochastic processes.

It should be noted that the EM-SDI does not perform the analysis or develop derived outputs based on different datasets It facilitate the modelling by holding the inputs to the model. This distinction is important because of the relative complexity involved in flood modelling. For example, I need a flood model done in as near to real time as possible, although the data may be available and any subsequently modelling can be made available via the EM-SDI, the exercise of performing the modelling itself is dependent on external services.

Similar to the chemical scenario above, during a flood event there is more of a strain on the health services. Thus, emergency mangers need to allocate, reallocate and distribute additional medical services to all those in need. The EM-SDI would contain information about hospitals and hospital resources (hospital beds, ambulance, doctors etc). This will better facilitate awareness about the resources or perhaps lack of resources available to handle the disaster.

4.3.3 Scenario 3: Biological Hazard

There is a large scale biological exposure as a result of something unknown. 1 physician in a hospital will be suspicious of a patient. The virus spreads well beyond the confines of the hospital and is affecting people (to different degrees) all across the country and further afield.

There are three stages to the unfolding scenario;

- Illness is identified
- Mitigation measures are installed to limit exposure and contain the spread of the disease
- Illness goes beyond any level of containment and there is mass panic, services and infrastructure are seriously affected.

Scenario Timeline

Week 1 - Early warning	A physician at the ICU of a local county hospital identified 5 cases of unusual respiratory illness, 3 of whom died from severe and sudden onset of pneumonia and acute respiratory failure. During the next two days new cases are reported throughout the Province. Signs & symptoms include: Fever, myalgia, headache, chills 1-2d, followed by a non-productive cough and shortness of breath 5-7d after onset.
Week 2 - New cases identified in central	Three different hospitals in 2 large metropolitans in Europe report on growing number of patients presenting signs & symptoms of a particular disease. During the 2nd week hospitals reported on 200 cases of severe symptoms, 70 were admitted to the ICU, 25 of whom died.

Europe	Although cases are reported in all age groups, older people (>65) appear to be the most severely affected, with case-fatality rates approach 35%. Experts suggest it might be a deliberate biological attack, but there is no confirmation for this yet.
Week 2-3 - Public behaviour	The virus begins to make headlines and becomes the lead story on major news networks. Rates of absenteeism in schools and businesses begin to rise. Phones at physician offices and health departments begin to ring constantly. Exaggerated accounts of illness are reported by the media, the media suggest it may have been a deliberate attack. Widespread concern begins because vaccine is not yet available and supplies of antiviral drugs are severely limited. Elderly patients with chronic, unstable medical conditions are afraid to venture out for fear of becoming seriously ill with this disease. Family members are overwhelmed with grief and outraged when loved ones die within a matter of a few days.
Week 4 + - Pandemia	Police departments, local utility companies and mass transit authorities begin to have severe personnel shortages, resulting in severe disruption of routine services. Hospitals and outpatient clinics become short-staffed when physicians, nurses and other health-care workers become ill. Intensive care units at local hospitals are overwhelmed, and soon there are widespread shortages of mechanical ventilators for treatment of patients with pneumonia. Family members are overwhelmed with grief and outraged when loved ones die within a matter of a few days. Looting becomes a serious problem in major metropolitan areas due to shortages of police officers. Several major airports close because of high absenteeism among air traffic controllers. Further deterioration in health and other essential community services occurs over the next 4-8 weeks as illness sweeps across Europe.

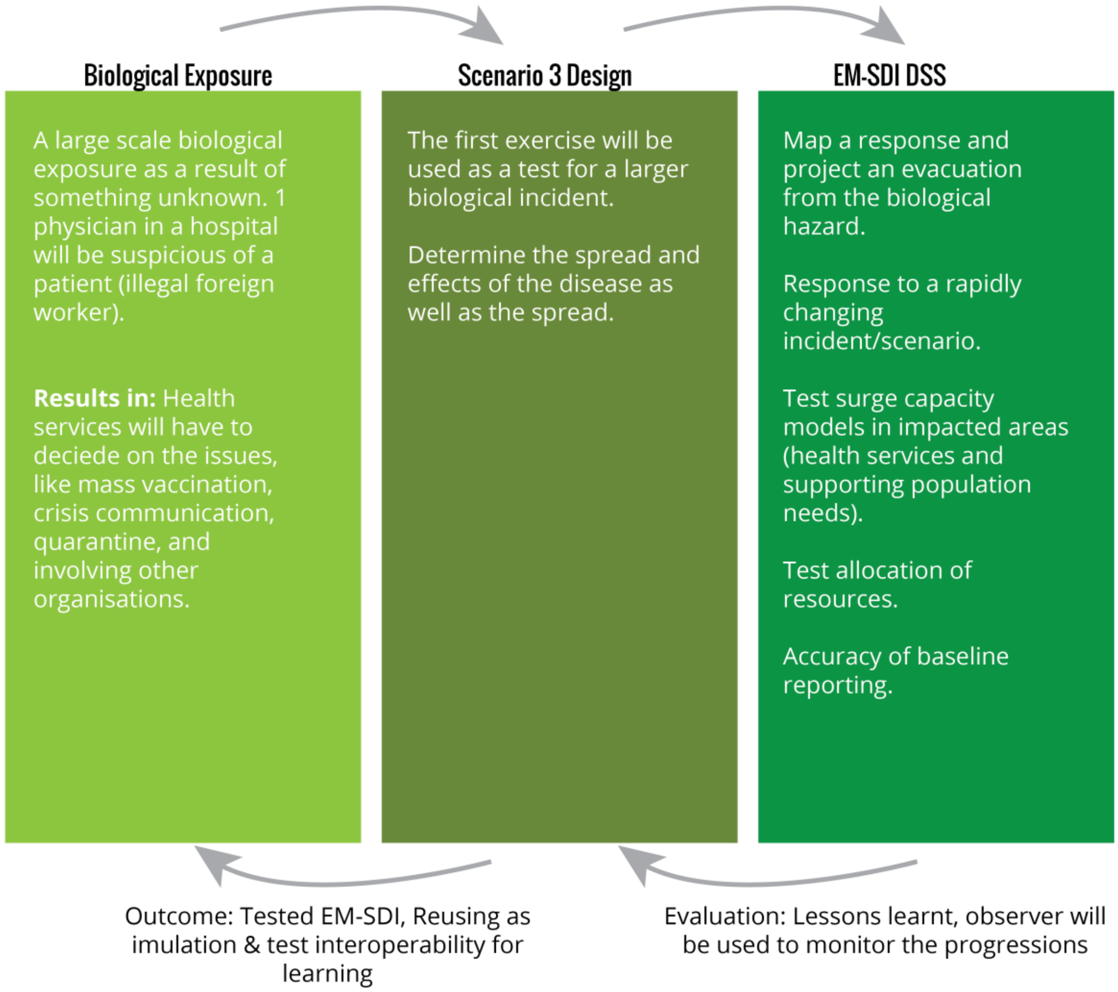

Figure 18: Scenario 3 Biological Exposure

This results in health authorities having to decide on the issues and how best to contain or mitigate against the virus. Specifically, if there is a need to mass vaccinate, or quarantine the populations (or segments of the population) to their homes to stop the spread of the virus.

4.3.3.1 Implementation of Scenario 3

The spread of a biological disease is quite different to the other 2 scenarios discussed. With the spread of a contagious disease it becomes less about modelling or understanding the physical or natural environment, but by contrast looks at people and the movement of people.

In this regard, the first exercise will be used as a test for a larger biological incident. The spread and effects of the disease must be determined. Equally, the response effort must be flexible enough to respond to a rapidly changing incident/scenario. The EM-SDI is used to assist in mapping a response and project an evacuation from the biological hazard. To test surge capacity models in impacted areas (health services and supporting population needs), and the allocation of resources.

So while the EM-SDI can attempt to predict the spread of a disease, because of the imperceptible nature of a virus, it is impossible to effectively track the spread. It operates based on trends and expectation, rather than fact. Thus, it is critical within a biological scenario that information is updated in a timely fashion. Moreover, in a biological scenario there is the macro level component of epidemiology and resource allocation, but also a significant micro level component in terms of how you ensure the safety of the existing affected population. Similar to the other 2 scenarios discussed, in the case of a virus there is more of a strain on the health services. Thus, emergency managers need to allocate, reallocate and distribute additional medical services to all those in need. The EM-SDI would contain information about hospitals and hospital resources (hospital beds, ambulance, doctors etc). This will better facilitate awareness about the resources or perhaps lack of resources available to handle the disaster.

A final issue, and it is present in the 3 scenarios is that of data formats. This issue presents itself in the analysis phase (as opposed to end user outputs). Depending on the type of modelling performed and the industry it relates to, there are drastically different proprietary software used to do analysis. In other words, if I am an engineer concerned with infrastructure modelling, I need CAD files of some sort. By contrast, If i am an epidemiologist I need data in shapefile or other GIS formats to perform my analysis. This project took the main proprietary formats used, converted each dataset to each of these offline using a feature manipulation engine (FME). This caters for most potential users but is largely inefficient and in the real world and engineer will do his/her analysis and upload in their own format only. This means that epidemiologist cannot use the engineers data to inform their analysis as the two formats are not compatible. An improved system would look at creating an FME to do format conversions on the fly, thereby removing the onus on the individual to make files compatible for all users during a time critical disaster incident.

4.4 EVALUATION OF REQUIREMENTS

4.3.1.3 Evaluation of EM-SDI Tool for Scenario 1-3

This section will evaluate whether the EM-SDI worked effectively to address the requirements of the system for scenario 1-3;

Requirement	**Explanation**	
R01	In the world of emergency management / resilience / disaster management the lifecycle is described generally as stages of preparation (planning, training, exercising), response (detection, initial response, considered response) recovery (reconstitution, reconstruction, review & mitigation) with a closed feedback loop into preparation. It is important that the EM-SDI can function effectively across the entire cycle.	As a resource in place during a disaster, the information provided in general by an SDI is crucial in detection and informing the initial response of incident. Similarly, in this case the data contained with the EM-SDI would be a valuable asset in coordinating a response effort. The EM-SDI operate across all the phases of disaster management, not just when the disaster occurs. This means it's also useful outside of a disaster for knowledge growth and improving the ways and means by which we address disasters in the future.
R02	Tools spanning tiers of emergency management. Although an SDI typically focuses on the usefulness of its tools at the strategic level, in order for it to deliver the necessary situational awareness to support informed decision making it is vital that the toolset either permeates to lower tiers of management or integrates with systems that already exist at lower tiers of management.	The system has been built with all potential users in mind. In this regards, the system is easy to navigate through and quite user friendly. Given this size of some the data, latency and speed issue occurred when downloading information even mobile networks. Based on the type of end user and devices at their disposal this could present issues in deliver on-time responses.
R03	The spatial data stored on the system must be highly interoperable.	This was a known issue prior to initiating prototype development. In short, although attempts were made to speed up the channels through which end users can extract information there are still many

		limitations in terms of formats and way information can be extracted from the system and used by the various stakeholders.
R04	EM-SDI offers multiple operations for editing the visualization. Users should be able to at least add, delete, rotate and move entities. Users are able not only to edit the visualization, but to directly manipulate data through visualization.	All of these features are typical of SDIs and as such were added to the EM-SDI.
R05	EM-SDI is able to present contextual data and spatial relationships effectively	It was judged that the map interface would facilitate this relationship. Using the map end users could navigate through map elements and layers to see data on infrastructure, services, population and other key datasets.
R06	The ability to manage information, which can be done in several different ways. Log of events and actions taken may be recorded automatically in relation to time and date, making it easier to access data at a later stage.	As not to complicate this requirement the EM-SDI had a 'Favorites' button located on each dataset uploaded to it. This was joined to the account login and a favourites panel was located in the upper right corner of the homepage for easy access to previously used datasets.
R07	The ability to provide portable resources such as portable laptops, or have access points in the mobilising vehicle, which allows command units to access information from the 'at scene'.	EM-SDI was built to be used across all device types. It was noted that this was more effective as you scale up the device and environment in which the device is in. Very efficient for desktops in HQ, compromised effectiveness for mobile devices on 3G or lower data transfer speeds.
R08	EM-SDI offers extensive and effective query possibilities. Users should be able to execute queries both graphically and textually.	User Interface operated as intended. Easy to navigate to the required dataset. Users can select by theme or the type of data they want or by geographic area. This layout has the added advantage of allowing the user to select specific spatial locations from which they can pinpoint and extract relevant information.
R09	The ability to operate the software and access data. It is convenient to ensure that all trained users are able to use the software without any restrictions. However this means the data and information is available to everyone and anyone and this can be seen as being irresponsible. Assigning usernames and possible passwords assures safety and privacy of low and high priority information.	Requires little prior knowledge of existing SDI, jut a simple keyword search of theme or bounding box for spatial location. There are no other elements on the UI to confuse or distract a user of the system. Currently datasets are set up as predefined spatial units or parcels. When you query data from the database you get the collection of files that were uploaded. This may be ideal for certain analyses but you may require only a subset of this data. The ability to subdivide existing spatial files dynamically would be an excellent addition to this system but is currently not supported.

R10	EM-SDI should be easy to use. Usability issues are taken into consideration in the design process of the user interface.	The principles of usability design were heavily considered prior to system development. Specificaly, possible issues surrounding learnability, efficiency, memorability of the system, and operating without errors. User Interface easy to navigate to the required dataset. There are few steps involved from getting from the homepage to the final dataset (3 steps).
R11	The system must be web-based and accessible on multiple forms of desktop and portable devices	EM-SDI operated effectively on all desktop systems tested as well as on mobiles. The mobile interface was very sluggish and the map UI elements were not as effective on the smaller screens
R12	Given the nature of spatial data (large size) it will be important for prospective systems to find a way to segment data based on a users tailored requirements	Some data sources are quite clunky, the Digital Elevation Model (DEM). As one of the requisites of the plume modelling the DEM required significant time to download and required pre-processing before input into the model. Ideally, a user can select the area of interest, no matter how small, and extract just as much information as they require from the system.

The impacts of some disasters may be slow, some may be instantaneous. The EM-SDI caters for the longer term objectives a little better than the short term ones. The absence of the ability model data within the system I would foresee certain problem with, and potentially a disconnect occurring. In order for there to be buy-in to any system it needs to be integrated and seamless. Future systems would need to either establish parallel modelling systems online to handle on-demand requests. Once this occurs, and the outputs are pushed back into SDI it would ensure all stakeholders involved in the response are getting the same information.

The standard system architecture highlights the inherent contextual stumbling blocks that could exist when using a system in practice. You can't apply a one-size fits all approach when developing an SDI for emergency management. The problem is that when you employ the current rules for SDI development, you get a system that operates perfectly in an office somewhere with high speed internet and great facilities, but on the ground during/post-disaster there would be visible limitations in terms of devices, general compatibility, and data transfer issues. Moreover, there currently there exists a 1-size fits all approach to data management. This results in there being silos of information per organisation whic becomes wasterful in terms of data storage, data access and from a users perspective find the right data for them can become laborious.

Interoperability must be the cornerstone of any SDI framework design for emergency management. For instance, to be effective the EM-SDI needs to collate, manage and transfer disparate structured and unstructured data sources as well as interfacing with existing frameworks in a complimentary manner in order to enhance 'picture building' and inform decision making. Economies of scale need to be 'exploited' in terms of data pooling and the effectiveness and efficiency of the data transfer process.

Scalability and transferability are further key dynamics of building a coherent SDI. Scalability refers to the size and impact of the crisis whereas transferability is concerned with the type of crisis event. Many of the underpinning datasets required to respond to different types of crisis remains consistent. Moreover, event severity will have implications for the volumes and duration of data requirements as well as resource allocations, nonetheless from a data Any platform that is developed must have the capacity to deal with 'less severe' crisis events as well as having the potential to be 'scaled up' in the advent of an extreme event. This is an important consideration within the confines of the EM-SDI concept and i would envisage have a major determinant on application capacity.

Transferability, scalability and interoperability will determine the 'end-user market' for the EM-SDI. In order to deliver added value, the EM-SDI must also look to go beyond these characteristics in terms of efficiency of these system with respect to theory operational environments.

5.0 CONCLUSION

6.1 INTRODUCTION

This chapter commences by presenting a review of research findings derived from an analysis of primary empirical and secondary information undertaken in three of the preceding chapters. It proceeds to present a comprehensive and progressive discussion on these findings and their implications for Spatial Data Infrastructures and also for wider academic discourse on their application within the Emergency Management, with the stated aim of providing answers to the research questions which were advanced at the beginning of the research process. This final chapter will conclude by advancing a number of recommendations for future proactive engagement with end-users on contextual requirements of SDIs for disaster relief.

6.2 REVIEW OF RESEARCH FINDINGS

This research set out to initially determine the connection and history of research that exists for data usage within emergency management (in contrast to the traditional applications for SDI over the past decade). Moreover, to simultaneously evaluate the origins, evolution, function, role and defining characteristics of such areas. Subsequent research questions centred on an evaluation of the nature and extent of the relationship between the SDI for emergency management and the issues that exist therein, in terms of accessibility, data harmonisation through international, and national emergency planning, as well as in terms of the operation of planning practice at a micro first responder level.

This study aimed at the construction of a prototype software tool which is able to interactively visualize and interrogate spatial data within the domain of emergency management. This tool was implemented in a development process which was divided into two sub-processes: specification and implementation. In the specification process, a description of the target state was produced, and in the implementation process this state was realised. Overall, the development process was successful and the work proceeded without any significant problems or delays. At the end of the study, the implemented approach was validated via scenario based assessment.

The research problem of the study was defined as the following:

How can improvements in architecture be made to SDIs in order to tailor them for large scale emergency planning?

The research problem was solved by answering the following three research questions:

1. *What special requirements does an SDI for emergency management have?*
2. *How should information be presented and managed within the SDI?*
3. *How should the interaction be implemented and managed?*

The first question was answered by examining the theory of SDIs (in general), but also how they have been applied in the emergency management space. What I ultimately found the most useful was in particular how they have been applied commercially and in European funded research programmes. This took the SDI architecture one step forward and created real world applications. A barrier I kept finding was that within academic research theory, on either emergency management or SDI development, each explained what should happen in an ideal scenario (i.e. the right data, getting to the right people, at the right time). In reality, this can be far more complex and is certainly more challenging owing to any number of issues (organisational, infrastructural, societal, and technological). Thus, having both the traditional, academic review and the commercial or research funded sides added depth to the overall study.

The collation, effective management and timely transfer of robust and credible data impact all activities and transcend all phases of the disaster cycle. All actors involved in recovery and reconstruction are dependent upon data in order to inform decision making, prioritise and mobilise resources as well as to measure the impact of interventions and response strategies. However in spite of the recognised importance of data transfer in terms of resilience, preparedness and responsiveness to a disaster it is apparent that the efficiency of disaster intervention and planning continues to be undermined by ineffective collaboration and constraints on information sharing between the various actors that constitute the responder community.

There are many sources of data and a multitude of estimation methods of related information relevant to disaster related incidents, nonetheless the tendency has been for responders and relief agencies to go for the most available information without appropriate concern as to its reliability, timeliness or indeed its capacity to most effectively address information needs cross different phases of the disaster cycle. Consequentially, the key 'information vacuum' within the confines of disaster recovery and reconstruction does not always pertain to the unavailability of data but to the lack of harmonisation (between structured and unstructured datasets) as well as limitations around the interoperability of prevailing but often disparate data frameworks. The proof of concept EM-SDI platform that has been developed for this dissertation does not address the entire multitude of issues that a potential SDI must overcome in this space, but does aims to bolster decision making capacity by identifying data gaps in the current status quo.

6.3 RECOMMENDATIONS

Based on the scope and findings of the research underpinning this dissertation, it is clear that in order for the Spatial Data Infrastructures to take a much needed proactive role in leading the future growth and development evidence based planning in Emergency Management, researchers and government need to take a more assertive approach in trialing and working through issues, thereby broadening the theoretical foundations and empirical insights needed for effective institutional implementation.

In an effort to progress from the points made in the previous discussion, I will now put forward a number of recommendations for the Emergency management professionals to appropriately engage with technologists and SDI developers, in terms of the formulation of best practice measures and proactive use of professional tools. Furthermore, while not all the measures advocated are SDI advancements in the traditional sense, the Emergency Planning provides an indispensable 'operational framework' for their implementation.

6.3.1 Context-Specific Engagement

It is submitted that a comprehensive understanding of the distinct context of the subject area needs to be established, if possible derived from empirical evidence. Future proactive engagement in the development of Spatial Data Infrastructures must be multidisciplinary and evolving from inception all the way to prototype development, release, and trials. It is envisioned that this knowledge on the inherent strengths and weaknesses of such areas, for example in terms of creating usable information for both high level incident commanders as well as first responders alike, will guide the formulation of the most appropriate and pertinent tailored methods and solutions in the future.

6.3.2 Create responsive systems

With the advent of more portable forms of technology and, in particular, the advantages using them bring for Emergency management, it is clear that they need to be compatible with such devices going forward. In this regard, front-end system need to be responsive and developed using Bootstrap or similar framework to ensure that the spectrum of end users can operate efficiently off one system.

6.3.3 Targeting data requirements with end-users

All data created in this world sits in proprietary formats. There is any number of these formats, and they change over time. As a town planner, it is important that any data I receive comes in ArcGIS compatible format, similarly, if I'm an engineer any form of analysis that is required of me is dependent on me having CAD data. Finally, if I am an on-the-ground first responder I don't care too much about raw data, I need outputs, 'how many beds are there in this hospital?' Any SDI must appropriately cater for each of these users (as well as dozens of others). The study finds that the best way to handle situations like this is to build a feature manipulation engine (FME). In other words a tool which can convert data from one format to another on-the-fly. This removes data size limitations in terms of having to house mountains of the same type of data. Instead an FME acts as export function allowing the user to select the required data (meanwhile the system only keeps that data in one format on their servers)

6.3.4 Coping with the size and complexity of spatial data

Data is collected in spatial units. Those units could be local, regional, national or international. Depending on the response efforts, size and scope of the disaster, perhaps only a small segment of these data aggregation scales is needed. Following on from the first point on internet speed, data streams must be as efficient as possible. In this regard, SDIs for emergency management need to be streamlined to facilitate data extraction based on spatial querying (i.e. cookie cut out relevant data to minimise data requirements). A user will seek to extract the minimal amount of data that can be used to make a decision. Depending on the type of scenario and the type of analysis being done there is any number of requisites on data if choosing environmental, social, or economic data.

Furthermore, given the spatial nature of the data, the Coordinate Reference Systems (CRS) it belongs to become extremely relevant. The earth is not flat. In order to show a map as a 'flat' output we typically apply a CRS to the data based on the part of the world it's in. When you operate an SDI at a wider scale you encounter issues with CRSs and in particular the variety of CRS that exist (typically each country has its own national one). The array of CRS means that user can be dealing with data sources are not being displayed correctly because of more or more of the projections.

In conclusion, it is submitted that the strategies recommended above have a broad applicability and are capable of being utilised in a wide range of future SDIs being developed. All that is required is that the conscious effort to really consider the architecture of the system. Although the data itself is the primary component for advancing aid and response efforts, in the absence of a stable system on which to hold and visualise the data it becomes redundant. It is envisioned that the implementation of such recommendations will foster a positive relationship between the Emergency management professionals and technologist crating these systems which has the potential to create a more productive, balanced and sustainable solutions for use in the future.

6.4 FURTHER RESEARCH

This study evoked numerous possible future research leads. As mentioned, the constructed approach is still in a prototype phase, requiring more prolonged research work.

As mentioned, EM-SDI is targeted especially at analyst and strategic decision makers who need contextual data in their work. A possible future research lead could be interviewing end users in order to get more detailed information on how EM-SDI could better support their work. Furthermore, EM-SDI could be extended by adding more dynamic elements to it, deviating from predefined scenarios. This more dynamic environment would enable more authentic and extensive service discovery or composition testing. In addition, the dynamic elements would improve the ability of this approach to simulate real world phenomenon and environments.

Currently EM-SDI presents almost a showcase of functionality in a prototype system. However, the different technology frameworks that were used to build this system are neither compatible with each other nor are they stable. Therefore, a possible research lead would be to find a suitable umbrella framework that can accommodate all the system functionalities.

In the future it would be interesting to research whether EM-SDI could be operationalised. This would mean that besides modelling and visualising spatial information, EM-SDI could provide a means to operate within real world physical environments.

BIBLIOGRAPHY

- Aboueljinane, L., Sahin, E. And Jemai, Z. (2013) A review on simulation models applied to emergency medical service operations. Computers & Industrial Engineering [Online] 66 (4), 734-750. Available from: www.sciencedirect.com/science/article/pii/S0360835213003100.
- Adeyemi, S., Demir, E. And Chaussalet, T. (2013) Towards an evidence-based decision making healthcare system management: Modelling patient pathways to improve clinical outcomes. Decision Support Systems [Online] 55 (1), 117-125. Available from: www.sciencedirect.com/science/article/diiS0167923613000092.
- Aktas, E., Ulengin, F. And Sahin, S. O. (2007) A decision support system to improve the efficiency of resource allocation in healthcare management. Socio-Economic Planning Sciences [Online] 41 (2), 130-146. Available from: www.sciencedirect/science/article/pii/S0038012105000480.
- Alexander, D. (2002). Principles of emergency planning and management. New York: Oxford University Press
- Antonopoulou, E. Et Al. (2010) Web and mobile technologies in a prototype DSS for major field crops. Computer and Electronics in Agriculture [Online] 70 (2), 292-301. Available from: www.sciencedirect.com/science/article/pii/S0168169909001537.
- Araz, O. M. And Jehn, M. (2013) Improving public health emergency preparedness through enhanced decision-making environments: A simulation and survey based evaluation. Technological Forecasting & Social Change [Online] 80 (9), 1775-1781. Available from: www.sciencedirect.com/science/article/pii/S0040162512002442.
- Arora, H., Raghu, T. S. And Vinze, A. (2010) Resource allocation for demand surge mitigation during disaster response. Decision Support Systems [Online] 50 (1), 304-315. Available from: www.sciencedirect.com/science/article/pii/S0167923610001569.
- Aschenbruck, N., Gerhards-Padilla, E. And Martini, P. (2009) Modelling mobility in disaster area scenarios. Performance Evaluation [Online] 66 (12), 773-790. Available from: www.sciencedirect.com/science/article/pii/S0166531609001072
- Azizova, D. (2012) Disaster Management and its Economic Implications, Diploma thesis, University of Vienna, Austria.

- Bayntun, C., Rockenschaub, G. & Murray, V. (2012). Developing a health system approach to disaster management: A qualitative analysis of the core literature to complement the WHO Toolkit for assessing health-system capacity for crisis management. PLoS Curr, 4**,** e5028b6037259a.
- Bharosa, N., Lee, J., & Janssen, M. (2010). Challenges and obstacles in sharing and coordinating information during multi-agency disaster response: Propositions from field exercises. Information Systems Frontiers, 12(1), 49-65.
- Biddinger, P. (2012) Medical and Health Incident Management (MaHIM) System *available at www.gwu.edu/~icdrm*
- Blistanova, M. Et Al (2014) Data Preparation for Logistic Modelling of Flood Crisis Management. Procedia Engineering [Online] 69, 1529-1533. Available from: www.sciencedirect.com/science/article/pii/S187770581400397X.
- Bossaert, L. L. 1993. The complexity of comparing different EMS systems--a survey of EMS systems in Europe. Ann Emerg Med, 22**,** 99-102.
- Bradley, E.H., Curry, L.A., Devers, K.J. (2007). Qualitative data analysis for health services research: Developing taxonomy, themes, and theory, Health Services Research, 42(4), 1758-1772.
- Burkle,F.A and Greenough, G. (2008). Impact of the Public Health Emergencies on Modern Disaster Taxonomy, Planning and Response, Journal of Disaster Medicine and Public Health Preparedness, Vol.2/No.4.
- Carver, L., & Turoff, M. (2007). Human-computer interaction: the human and computer as a team in emergency management information systems. Communications of the ACM, 50(3), 33-38.
- Chatterjee, S. Et Al. (2009) Examining the success factors for mobile work in healthcare: A deductive study. Decision Support Systems [Online] 46 (3), 620-633. Available from: www.sciencedirect.com/science/article/pii/S0167923608002029.
- Chen, A. Y., Peña-Mora, F. And Ouyang, Y. (2011) A collaborative GIS framework to support equipment distribution for civil engineering disaster response operations. Automation in Construction [Online] 20 (5), 637-648. Available from: www.sciencedirect.com/science/article/pii/S0926580510002153
- Coppola, D (2011). Introduction to Disaster Management, Second Edition, ISBN 978-0-12-382174-4.

- Dabbish, L., & Kraut, R. (2008). Research Note—Awareness Displays and Social Motivation for Coordinating Communication. Information Systems Research, 19(2), 221-238.
- de Lanerolle, T. R. et al. (2010) Development of a virtual dashboard for event coordination between multiple groups. In: 7th International ISCRAM Conference, May 2010,Seattle, USA. Available from: www.iscram.org/ISCRAM2010/Papers/262-deLanerolle_etal.pdf
- Deak, G. Et Al. (2013) IoTs (Internet of Things) and DfPL (Device-free Passive Localisation) in a disaster management scenario. Simulation Modelling Practice and Theory [Online] 35, 86-96. Available from: www.sciencedirect.com/science/articles/pii/S1569190X13000415
- Dorasamy, M., Raman, M. And Kaliannan, M. (2013) Knowledge management systems in support of disasters management: A two decade review. Technological Forecasting & Social Change [Online] 80 (9), 1834-1853. Available from: www.sciencedirec.com/science/article/pii/S004016251200323X
- Dubbs, N.L., Bazzoli, G.J., Shortell, S.M., Kralovec, P.D. (2004). Reexamining organizational configurations: An update, validation, and expansion of the taxonomy of health networks and systems, Health Services Research, 39(1), 207-220.
- European Union. 2012. The European Civil Protection Training Programme [Online]. Belgium: Luxembourg: Publications Office of the European Union, 2012. Available: http://ec.europa.eu/echo/civil_protection/civil/prote/pdfdocs/Training%20brochure.pdf.
- Fischhoff, B. (2005). 'Scientifically Sound Pandemic Risk Communication, Gaps in the National Flu Preparedness Plan: Social Science Planning and Response'. Carnegie Mellon University.
- Fogli, D. And Guida, G. (2013) Knowledge-centered design of decision support systems for emergency management. Decision Support Systems [Online] 55 (1), 336-347. Available from:http://www.sciencedirect.com/science/article/pii/S016792361300050X.
- French, S., & Turoff, M. (2007). Decision Support Systems. COMMUNICATIONS-ACM, 50(3), 39.

- Friedrich, F., Gehbauer, F. And Rickers, U. (2000) Optimised resource allocation for emergency response after earthquake disasters. Safety Science [Online] 35 (1-3), 41-57. Available from: www.sciencedirect.com/science/article/pii/S0925753500000217.
- Griffin, L., & de Leaster, E. (2009). Social networking healthcare. IEEE 6th International Workshop on Wearable Micro and Nano Technologies for Personalized Health (pHealth) (pp. 75-78).
- Guhu-Sapir, D., Hoyois, P., Below, R. (2013) Annual Disaster Statistical Review 2012: The numbers and trends [Online]. Available: cred.be/sites/default/files/ADSR_2012.pdf
- Gupta, A. And Sharda, R. (2013) Improving the science of healthcare delivery and informatics using modelling approaches. Decision Support Systems [Online] 55 (2), 423-427. Available from: http://www.sciencedirect.com/science/article/pii/S0167923612002564.
- Hadiguna, R. A. et al. (2014) Implementing a web-based decision support system for disaster logistics: A case study of an evacuation location assessment for Indonesia. International Journal of Disaster Risk Reduction [Online] 9, 38-47. Available from: http://www.sciencedirect.com/science/article/pii/S2212420914000193.
- Haghighi, P.D, Burstein, F., Arbon, P, & Zaslavsky, A. (2012). Using Ontology for IT-enabled Comprehensive Management of Mass Gatherings, DSS 2012 Conference – the 16th IFIP WG 8.3 International Conference on Decision Support Systems, Athens, Greece.
- Hamedi, M., Haghani, A. And Yang, S. (2012) Reliable Transportation of Humanitarian Supplies in Disaster Response: Model and Heuristic. Procedia - Social and Behavioral Sciences [Online] 54, 1205-1219. Available from: http://www.sciencedirect.com/science/article/pii/S1877042812042978.
- Heuer, R. J. (1999). Psychology of intelligence analysis. New York, NY: Novinka/Nova Science.
- Hosack, B., Hall, D., Paradice, D., & Courtney, J. F. (2012). A Look Toward the Future: Decision Support Systems Research is Alive and Well. Journal of the Association for Information Systems, 13(5), 3.

- Hristidis, V. et al. (2010). Survey of data management and analysis in disaster situations. Journal of Systems and Software [Online] 83 (10), 1701-1714. Available from: http://www.sciencedirect.com/science/article/pii/S0164121210001329.
- Huang, M., Smilowitz, K. And Balcik, B. (2012) Models for relief routing: Equity, efficiency and efficacy. Transportation Research Part E [Online] 48 (1), 2-18. Available from: http://www.sciencedirect.com/science/article/pii/S1366554511000639
- Ivgin, M. (2013) The decision-making models for relief asset management and interaction with disaster mitigation. Int. Journal of Disaster Risk Reduction [Online] 5, 107-116. Available from: http://www.sciencedirect.com/science/article/pii/S2212420913000423
- Kohli, R. And Devaraj, S. (2004) Contribution of institutional DSS to organizational performance: evidence from a longitudinal study. Decision Support Systems [Online] 37 (1), 103-118. Available from: http://www.sciencedirect.com/science/article/pii/S0167923602002117.
- Kraus, M., Rauner, M.S., Schwarz, S. (2010) Hospital management games: a taxonomy and extensive review, Central European Journal of Operations Research, 18(4), 567-591.
- Kulawinak, M. And Lubniewski, Z. (2013) Safe City - A GIS-based tool profiled for supporting decision making in urban development and infrastructure protection. Technological Forecasting & Social Change [Online], In Press. Available Online from: http://www.sciencedirect.com/science/article/pii/S0040162513002163.
- Kumar, S. And Havey, T. (2013) Before and after disaster strikes: A relief supply chain decision support framework. Int. J. Production Economics [Online] 145 (2), 613-629. Available from: http://www.sciencedirect.com/science/article/pii/S0925527313002430.
- Lee, J., Bharosa, N., Yang, J., Janssen, M., & Rao, H. R. (2011). Group value and intention to use—A study of multi-agency disaster management information systems for public safety. Decision Support Systems, 50(2), 404-414.
- LEE, Y. M. (2009) Simulating Distribution of Emergency Relief Supplies for Disaster Response Opperations. Proceeding of the 2009 Winter Simulations Conference, 2797-2808. Available from: http://dl.acm.org/citation.cfm?id=1995837.

- Leifler, O. (2008) Combining Technical and Human-Centered Strategies for Decision Support in Command and Control: The ComPlan Approach. Proceedings of the 5th International ISCRAM Conference. Available from: http://www.iscramlive.org/dmdocuments/ISCRAM2008/papers/ISCRAM2008_Leifl....
- Liberatore, F. Et Al. (2014) A hierarchical compromis model for the joint optimization of recovery operations and distribution of emergency goods in Humanitarian Logistics. Computers & Operations Research [Online] 42, 3-13. Available from: http://www.sciencedirect.com/science/article/pii/S0305054812000809.
- Manoj, B. S., & Baker, A. H. (2007). Communication challenges in emergency response. Communications of the ACM, 50(3), 51-53.
- Mendonça, D., Jefferson, T., & Harrald, J. (2007). "Collaborative adhocracies and mix-and-match technologies in emergency management". Communications of the ACM, 50(3), 44-49.
- Miniati, R., Capone, P. And Hosser, D. (2014). Decision support system for rapid seismic risk mitigation of hospital systems: Comparion between models and countries. Int. Journal of Disaster Risk Reduction [Online] 9, 12-25. Available from: http://www.sciencedirect.com/science/article/pii/S2212420914000296.
- Neville, K. & Healy, M. (2009) A Teaching Case: Towards Bridging Disciplinary Divides in IT Education 17th European Conference on Information Systems - conference proceeding, Verona, Italy.
- Neville, K., Woodworth, S., & O'Sullivan-Rochford, C. (2012). A Three-Disciplined Approach to the Development of a Financial Learning Management System (FinLMS). Fusing Decision Support Systems Into the Fabric of the Context, 335.
- OCHA. 2006. UNDAC Training handbook [Online]. Available: http://www.unocha.org/what-we-do/coordinationtools/undac/methodology-training.
- Oloruntoba, R. (2013) Plans never go according to plan: An empirical analysis of challenges to plans during the 2009 Victoria bushfires. Technological Forecasting and Social Change [Online] 80 (9), 1674-1702. Available from: http://www.sciencedirect.com/science/article/pii/S0040162512003174.
- Pearce, T. (2008). 'Communication as core business'. The Australian Journal of Emergency Management, Vol. 23(3). 2.

- Pfefferbaum, B., Flynn, B. W., Schonfeld, D., Brown, L. M., Jacobs, G. A., Dodgen, D., Donato, D., Kaul, R. E., Stone, B., Norwood, A. E., Reissman, D. B., Herrmann, J., Hobfoll, S. E., Jones, R. T., Ruzek, J. I., Ursano, R. J., Taylor, R. J. & Lindley, D. 2012. The integration of mental and behavioral health into disaster preparedness, response, and recovery. Disaster Med Public Health Prep, 6, 60-6.
- PHECC 2011. Education and Training Standards.
- Rao, M. et al. (2007) A web-based GIS Decision Support System for managing and planning USDA's Conservation Reserve Program (CRP). Environmental Modelling & Software [Online] 22 (9), 1270-1280. Available from: http://www.sciencedirect.com/science/article/pii/S1364815206001988.
- RECOBIA D3.2 (2012). Deliverable D3.2 of the RECOBIA project (FP7-SEC-20 11-285010)
- Reynolds B.W. & Seeger M.W., (2005). 'Crisis & Emergency Risk Communication as an Integrative Model'. Journal of Health Communication. 10, 43-55.
- Rodríguez, J.T., Vitoriano, B. And Montero, J. (2010) A natural-disaster management DSS for Humanitarian Non-Governmental Organisations. Knowledge-Based Systems [Online] 23 (1), 17-22. Available from: http://www.sciencedirect.com/science/article/pii/S0950705109001117.
- Rodríguez, J.T., Vitoriano, B. And Montero, J. (2012) A general methodology for data-based rule building and its application to natural disaster management. Computers & Operations Research [Online] 39 (4), 863-873. Available from: http://www.sciencedirect.com/science/article/pii/S0305054809003104.
- Rolland, E. Et Al. (2010) Decision support for disaster management. Operations Management Research [Online] 3 (1-2), 68-79. Available from: http://link.springer.com/article/10.1007/s12063-010-0028-0.
- Schryen, G. And Wex, F. (2012) IS Design Thinking in Disaster Management Research. 45th International Conference on System Sciences [Online], 4102-4111. Avaibalbe from: http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=6149395&url=http%3
- Sen, A. Et Al. (2012) Clinical decision support: Converging toward an integrated architecture. Journal of Biomedical Informatics [Online] 45 (5), 1009-1017. Available from: http://www.j-biomed-inform.com/article/S1532-0464%2812%2900098-6/abstract.

- Suh, W., Hunter, M.P. And Fujimoto, R. (2014) Ad hoc distributed simulation for transportation system monitoring and near-term prediction. Simulation Modelling Practice and Theory [Online] 41, 1-14. Available from: http://www.sciencedirect.com/science/article/pii/S1569190X13001548.
- Technisches Hilfswerk 2006. Promotion of volunteers in european civil protection: Project Report, Technisches Hilfswerk.
- Varshney, U. Et Al. (2014) A model for improving quality of decisions in mobile health. Decision Support Systems [Online] 62, 66-77. Available from: http://www.sciencedirect.com/science/article/pii/S016792361400102X.
- Vescoukis, V., Doulamis, N. And Karagiorgou, S. (2012) A service oriented architecture for decision support systems in environmental crisis management. Future Generation Computer Systems [Online] 28 (3), 593-604. Available from: http://www.sciencedirect.com/science/article/pii/S0166361509002152.
- Wendt, K., Cortés, A. And Margalef, T. (2013) Parameter calibration framework for environmental emergency models. Simulation Modelling Practice and Theory [Online] 31, 10-21. Availbable from: http://www.sciencedirect.com/science/article/pii/S0166361509002152.
- Wex, F. Et Al. (2014) Emergency response in natural disaster management: Allocation and scheduling of rescue units. European Journal of Operational Research [Online] 235 (3), 697-708. Available from: http://www.sciencedirect.com/science/article/pii/S0377221713008527.
- WHO. 2008. Emergency Medical Services Systems in the European Union [Online]. Available: http://www.euro.who.int/__data/assets/pdf_file/0016/114406/E92038.pdf.
- Wiedener, M.J. And Horner, M.W. (2011). A hierarchical approach to modelling hurricane disaster relief goods distribution. Journal of Transport Geography [Online] 19 (4), 821-828. Available from: http://www.sciencedirect.com/science/article/pii/S096669231000164X.
- Yang, L., Yang, S.H. And Plotnick, L. (2013) How the internet of things technology enhances emergency response operations. Technological Forecasting and Social Change [Online] 80 (9), 1854-1867. Available from: http://www.sciencedirect.com/science/article/pii/S0040162512001801.

- Yates, D., & Paquette, S. (2011). Emergency knowledge management and social media technologies: A case study of the 2010 Haitian earthquake. International Journal of Information Management, 31(1), 6-13.
- Yi, T. And Zhu, Q. (2014) Simulation and application of disaster spread model in Chemical Disaster Network. Journal of Loss Prevention in the Process Industries [Online] 27, 130-137. Available from: http://www.sciencedirect.com/science/article/pii/S0950423013002362.
- Zerger, A. And Ingle Smith, D. (2003) Impediments to using GIS for real-time disaster decision support. Computers, Environment and Urban Systems [Online] 27 (2), 123-141. Available from: http://www.sciencedirect.com/science/article/pii/S0198971501000217.