Framework for Embedding Industry 4.0 in UAE Emergency Management

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Declaration

I hereby declare that:

1. I have not been enrolled for another award of the University, or other academic or professional organisation, whilst undertaking my research degree.

2. None of the material contained in the thesis has been used in any other submission for an academic award.

3. I am aware of and understand the University's policy on plagiarism and certify that this thesis is my own work. The use of all published or other sources of material consulted have been properly and fully acknowledged.

4. The work undertaken towards the thesis has been conducted in accordance with the SHU Principles of Integrity in Research and the SHU Research Ethics Policy.

5. The word count of the thesis is 35038

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Acknowledgement

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ABSTRACT

Disasters, natural and man-made, are on the increase. It is universally accepted that global warning and climate change drive the rate and the severity of natural disasters. Rapid industrialisation, regional conflicts and socio-political tensions are increasing the occurrences of man-made disasters. Emergences created by these disasters need to be handled efficiently and effectively to reduce the impact on affected communities. Emergency Management Cycle with four phases (mitigation-preparedness-response-recover) is the de-facto approach in handling such emergencies.

Although the UAE is not known for large-scale disasters, the underlying risk factors are increasing. The inception of Industry 4.0 gives an impetus to explore the use of the latest technologies in emergency management. An extensive review of literature concludes that no formal framework exists to integrate Industry 4.0 technologies in emergency management. Therefore, this research aims to design and develop a framework to facilitate the integration of Industry 4.0 technologies in the UAE National Response Framework.

With the justification of the research through the extensive literature review, the thesis presents a comprehensive analysis of data collected from interviews and a questionnaire survey. Driven by the gaps and potential enhancements identified through those two exercises, this work continues to assess the probable use of industry 4.0 technologies in emergency management and analyse existing Industry 4.0 Readiness Models. The outcomes from the assessment and analysis are then used to build the I4EM (Industry 4.0 for Emergency Management) Framework, which incorporates four (4) major constructs, *I4EM Application Repository, I4EM Technology Map, I4EM Readiness Model* and *I4EM Maturity Model*. Three (3) reference models for Key Performance Indicators (KPI), knowledge management and digital twins are also added to realise the full potential of the I4EM Framework.

The I4EM framework, together with three reference models, provides a holistic approach to integrating Industry 4.0 technologies in emergency management cycles and they collectively make a significant contribution to the body of knowledge in this field. As the government of the UAE has launched (in 2021) an ambitious strategy to become a global hub for Industry 4.0 technologies, the outlook for further research and development in this area is promising.

Table of Contents

List of Abbreviations

Abbreviation	Meaning
ADPC	Provides a framework for understanding the causes of disaster
BIM	Building information model bind
BSI	The British Standards Institute
CBR	Case-Based Reasoning
CC	Cloud Computing
CEMC	Crisis and Emergency Management Conference
CFF	Critical Failure Factors
CRED	The Centre for Research on the Epidemiology of Disasters
CSF	Critical Success Factors
DARPA	Defense Advanced Research Projects Agency
DEMATEL	Identifying Key Performance Indicators to be used in Logistics 4.0 and Industry 4.0 for the needs of sustainable municipal logistics by means of the method
DIMS	Disaster Information Management Systems
DPLG	Pre-Disaster risk-reduction phase and post-disaster recovery stage
DRI	Disaster Recovery Institute International
DSS	Specific decision support system
EMDAT	Emergency Events Database
EMISARI	Emergency Management Information Systems and Reference Index
EWS	The National Early Warning System
F-A	Fully achieved
GCC	Gulf Cooperation Countries
GIS	Geographic information systems
4IR teams	Globally collaborative research with the UAE
GPS	The global positioning system
I4EM	Industry 4.0 for Emergency Management
IATA	The International Air Transport Association
IBM	International Business Machines Corporation
ICT	Information and communications technology
I4EM	Industry 4.0 emergency management
I4EM	Indicators in Emergency Management Maturity Model
IMASH	Information management system for emergencies caused by hurricanes
IMPULS	The main objective of the study was to build a simple and user-friendly system
IoT	Internet of things
IT	Information Technology
KPIs	Key Performance Indicators
MENA	Middle East and North Africa
N-A	Not achieved
NCEMA	National Emergency Crisis and Disasters Management Authority
NGO	Government agencies, emergency services and volunteers

NRF	National Response Framework
NSDI	National Spatial Data Infrastructure
Nvivo	Qualitative data analysis platform (NVivo is a qualitative data analysis (QDA) computer software package produced by QSR International).
P-A	Partially achieved
Radical	Fundamental change
RFID	Radio-Frequency Identification
SAARP	Sensor-smart Affordable Autonomous Robotic Platforms
SAFE	Smart Augmented Field for Emergency
Sahana	Reports the development of an integrated system, "Sahana" in Sri Lanka
SAR	Silicon Valley-based Consultancy Services
SARMaster	Smart Structural Health Monitoring Systems
SI	Systems Integration
SMS	Short Message (or Messaging) Service
SPICE-based MM	Based Maturity Model Software Process Improvement and Capability Determination
SWOT	SWOT (strengths, weaknesses, opportunities, and threats) analysis is a framework used to evaluate a company's competitive position and to develop strategic planning.
THEMIS	Distributed Holistic Emergency Management Intelligent System
TQM	Total Quality Management
TRA	Telecommunications Regulatory Authority
Twin	Digital twins
UAE	United Arab Emirates
UAVs	Unmanned Aerial Vehicles
UN	United Nation
VDMA IMPULS Model	The Mechanical Engineering Industry Association is the largest network for mechanical engineering in Germany and Europe, the base model for generating a maturity model for the emergency management sector.
WAM	Web access management (Emirates News Agency)
WMG	Warwick Manufacturing Group
WSN	Wireless Sensor Network

List of Figures

List of Tables

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Chapter 1: Introduction

1.1. Introduction

The primary purpose of this chapter is to present the background to the formulation of the research aim and objectives. Following a brief introduction to disasters and emergency management, this chapter sets out the need for developing a framework for transforming the UAE emergency management system by embedding emerging technologies offered by frameworks such as Industry 4.0. A brief summary of the use of technologies in emergency management is presented to highlight their increasing role. An overview of the thesis is also provided with short introductions to all subsequent chapters.

1.2. Disasters

Since the beginning of mankind, disasters have been a regular occurrence. Earthquakes, floods, and hurricanes, for example, are some well-known natural disasters that often cause significant impact on individuals, communities, and societies (Kondratyev et al., 2006)**.**For example, in 2017, just two disasters, the Hurricane Maria in the Dominican Republic and the earthquake in Mexico, caused hundreds of deaths and significant damage to local infrastructure and communities (Hu & Smith, 2018) and (Singh et al., 2018).

Natural disasters impact local communities and can also cause a widespread impact on national economies and lead to long-term environmental damage (Botzen, Deschenes, & Sanders, 2019). Natural disasters such as earthquakes are by default natural, i.e., it is not possible to take preventative actions to stop an earthquake. But there is evidence that the frequency of natural disasters is increasing due to global warming (Herndon, 2017), which is caused by the actions of humans. However, it is difficult to distinguish whether natural disasters are purely natural or caused by human-induced factors.

While it is difficult to establish whether some natural disasters result from human-induced actions, humans are undoubtedundoubtedly responsible for man-made disasters. From the beginning of mankind, humans have caused many disasters by their actions. Wars between nations and/or various factions are the best examples. Two world wars and many other regional/national conflicts have led to millions of deaths. Since World War II, large-scale wars have been diminishing but other forms of man-made disasters have been rising. In recent memories, the Exxon Valdez Oil Spill (Nixon & Michel, 2018) and the 9/11 terrorist attack (Lyon, 2003) are highly damaging disasters. Industrialisation has led to other forms of man-made disasters such as industrial accidents and transportation catastrophes have proliferated societies.

While many natural disasters are unavoidable, there is no end to man-made disasters. Regional/national tensions continue to cause wars, and other man-made disasters are also happening frequently.

1.3. Growing threats from disasters

Around the globe, the frequency of disasters is increasing at an alarming rate. For example, as shown in Figure 1.1, the number of world natural disasters has been steadily rising over recent years with ever-increasing casualties.

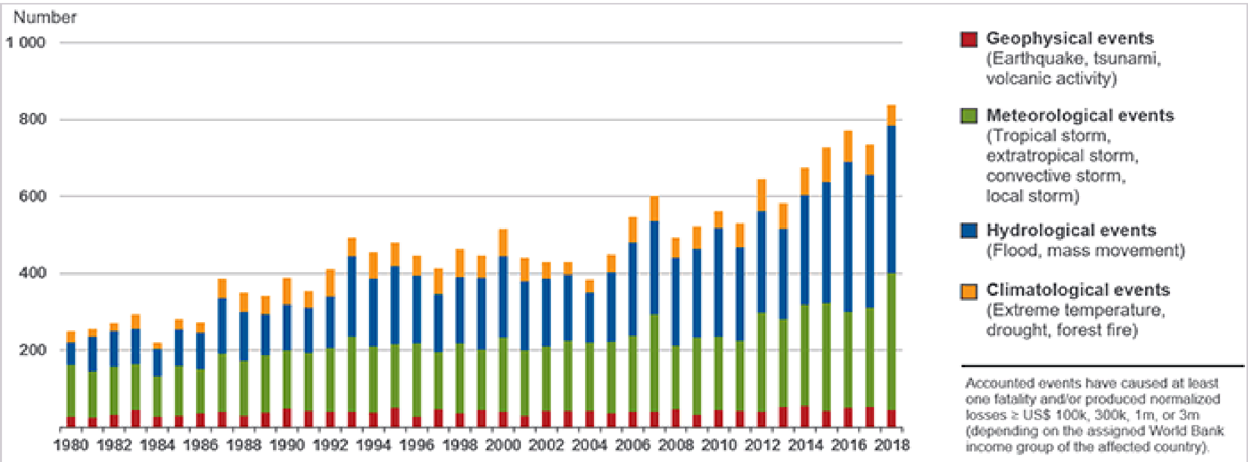


Figure 1.1: The number of world natural disasters (Insurance Information Institute, 2019)

Rapid urbanisation, ongoing geopolitical tensions and threats from radicalised groups continue to increase the risk of man-made disasters (Mazo, 2010). Insurance Information Institute (Insurance Information Institute, 2019.) reports that in 2016, manmade disasters counted for 41% of the total large-scale disasters around the world, which equates to 327 incidents.

1.4 Emergencies and Emergency Management

Whether natural or man-made disasters, they always lead to *emergencies* which means affected communities and societies will require additional resources and support to recover from the impact of disasters. Such efforts/support must be delivered in an organised manner to ensure the recovery is swift and well managed. This means that some pre-planning is required.

It appears that organised attempts at emergencies began only in the early 18^{th} century (Bullock, Haddow, & Coppola, 2017). Since then, the concept of "Emergency Management" gradually developed as an important and critical function across the globe. The evolution of emergency management approaches is well documented in many publications, such as Waugh & Streib,2006. As Chapter 2 provides further details of these approaches, they are not discussed in detail in here.

As shown in Figure 1.2, Contemporary Emergency management models typically have four phases: mitigation, preparedness, response, and recovery. It has been widely used to develop national response frameworks in many countries (Malcolm, 2010).

Figure 1.2: Four phases of Emergency Management (Malcolm, 2010).

Mitigation phase: This phase focuses on the actions that can be taken to reduce the probability of disaster occurrence and reduce the impact of disasters. Building appropriate flood defences is a good example of a mitigation measure (Krasko & Rebennack, 2017).

Typically, significant efforts are made in the mitigation phase as they may help to reduce the overall cost of emergencies (Renken, 2016).

Preparedness Phase*:* This phase aimis phase aims to develop plan(s) that outline the procedures/actions required to engage appropriate resources in handling emergencies caused by disasters. For example, every local council in the UK have plans to deal with various types of emergencies as required by the Civil Contingencies Act 2004 (Cabinet, 2012). For example**,** these plans typically outline what actions need to be taken by whom, how to manage communications between stakeholders involved and how other services/resources may be engaged. It may also refer to technologies/systems that may be used. For example, the UK government has produced detailed guidelines on how to use social media technologies in emergencies (UK Government, 2012)

Response Phase*:* When a disaster strikes, the response phase executes planned actions and other necessary measures to recover. For example, rapid construction of temporary shelters when normal dwellings are destroyed by events such as floods and earthquakes. As it is not possible to predict all consequences of a disaster in advance, some responses may be taken in situ.

Recovery Phase*:* Once the emergency is brought under control, the recovery phase focuses on further actions for a gradual return to normality. For example, providing the financial assistance required to deal with hardships caused by the disaster.

This generic model is seen as a reference point by researchers and those who are responsible for developing emergency plans. In Chapter 2, further details and alternative models are discussed in detail.

1.5 Technologies and Emergency Management

Over the centuries, mankind has been using technologies to transform how they live and work. For example, the invention of automotive vehicles greatly impacted mobility. In recent years, mobile technologies and devices have significantly transformed the way people work and behave (Shaheen & Cohen, 2018). As well as individuals, businesses also make efforts to embrace emerging technologies to improve the way they operate. So, it is fair to say that technologies are increasingly playing a greater role in every aspect of societies and industries.

Emergency management is no exception. Stakeholders of emergency management have also been using technologies. Communication technologies are probably the most used technology. Effective and efficient coordination during disasters is a prime necessity, and communication technologies play a vital role in connecting stakeholders and disseminating information in a coordinated manner. Other commonly used technologies include Geographical Information Systems (GIS) and Global Positioning System (GPS) for mapping, forecasting technologies to predict future events/incidents and computer models to analyse specific situations. In recent years, robotic devices and technologies such as IoT (Internet of Things) have been reported. Shaw (2020) provides a detailed insight into how different types of technologies have been assisting emergency management stakeholders over the last three decades.

It is argued that the 9/11 attack forced the USA and many other nations to embark on exploring the development and use of new technologies in emergency management cycles (Pine, 2017). The use of the latest communication technologies has been one of the critical deployments (Yates & Paquette, 2011**).** More recently, the popularity of social media technologies has been adopted to manage emergencs (Pine, 2017).

However, Shaw (2020) and Bullock et al., (2017) lament that the emergency management community has historically been slow to embrace new technologies. Initial literature reviews conducted for this research revealed that there is no systematic approach in existenceno to integrate new technologies into emergency management cycles. Several publications have highlighted the potential use of emerging technologies, but none of the publications suggests a coherent, methodical approach to embracing new technologies.

1.6 Emergence of Industry 4.0 technologies

When discussing -state-of-the-art technologies, Industry 4.0 should be at the forefront. It presents a set of rich technologies that could potentially lead to a radical transformation of how organisations work and perform. Although its roots go back to the manufacturing sector, many other sectors are now experimenting with Industry 4.0 technologies. For example, healthcare (Frank, Dalenogare, & Ayala, 2019) and public service sectors are already using some technologies to transform their operations. A recent publication from the World Economic Forum (Jacobides, Sundararajan, & Van Alstyne, 2019, February) argues that Industry 4.0 technologies could transform emergency management.

1.7 Disasters and emergencies in the UAE

The United Arab Emirates (UAE) is a union of seven emirates (or states). Each emirate is administered by an inherited emirate with a single national president for the whole of UAE. As shown in (Figure 2), UAE shares its boundaries with Saudi Arabia to the south, Oman to the east, and Iran and Qatar, towards the south-eastern border of the Arab Peninsula on the Persian Gulf.

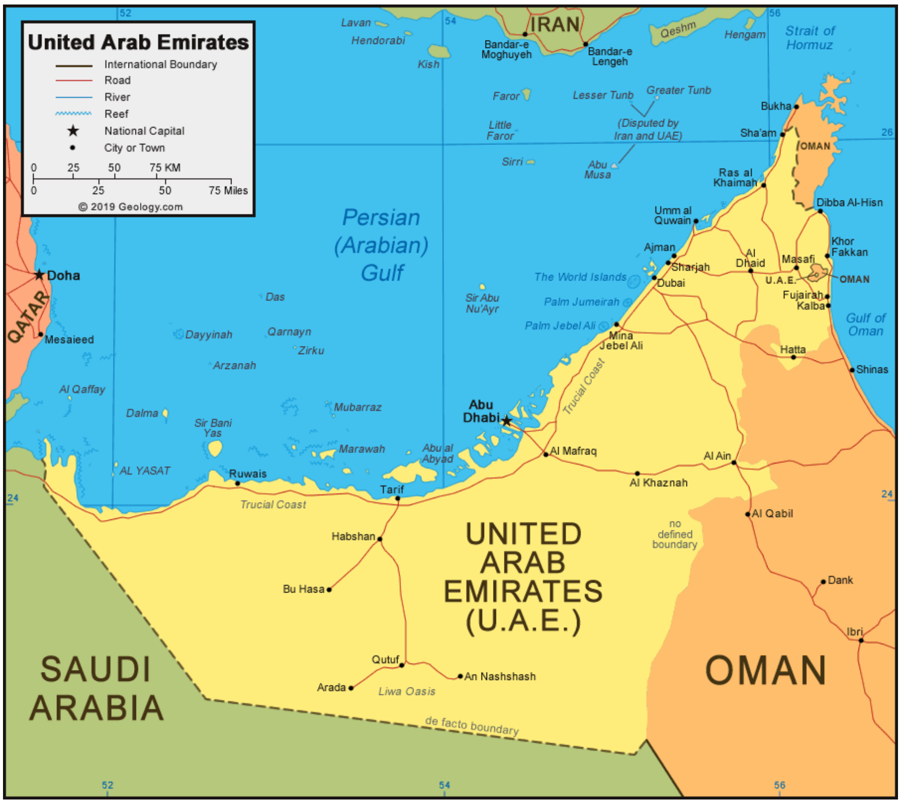


Figure 1.3: Map of United Arab Emirates (Geology.com, 2005)

With its ever-expanding economy, now recognised as a major power in the region, UAE's population growth has been unprecedented in recent years. It has been a magnet for professionals as well as low-skilled labour. Nearly 80% of the total population of 10 million are non-indigenous. By 2050 the UN expects this figure to reach 15.5 million (EUAEW, 2011). In addition to its location, ever-changing geo-political situations in the region and rapidly growing population have substantially increased the risk of disasters.

Although it is not widely publicised, there have been several major disasters in the UAE. The most recent incidents include floods, storms and earthquakes.

In terms of man-made disasters, they are mainly confined to the transport sector. Although there have been no major natural disasters in the UAE in recent years, several developments in the UAE and in the region may lead to man-made disasters.

Terrorism

Although there have not been any significant incidents relating to terrorism, the level of threat is ever increasing. UAE has listed nearly 100 organisations (WAM, 2014) as terrorist organisations. Terrorist attacks may cause major catastrophes.

Fast-changing Geo-politics

Geo-politics in the Middles East is fast changing. Ongoing conflicts such as wars in Yemen and Syria have escalated risks, and the UAE's stability might be affected.

Rapidly increasing population

Demographic changes especially increased population density and urbanisation, increase vulnerability to disasters (Charles, 2007).

Given these emerging threats and the increasing likelihood of natural disasters due to global climate changes, UAE needs to have a robust national framework for managing emergencies.

1.8. UAE National Response Framework

In 2007, UAE established the National Emergency, Crises and Disaster Management Authority (NCEMA) to coordinate the design, planning and implementation of a national framework for managing emergencies and disasters (Charles, 2007). In 2013, NCEMA developed the first National Response Framework (NRF), which outlines the response arrangement for all types of emergencies identified in UAE's National Risks and Threats Register (NCEMA, 2012. Alteneiji, 2015). As shown in (Figure 1.4), The National Response Framework provides guidance on four different aspects.

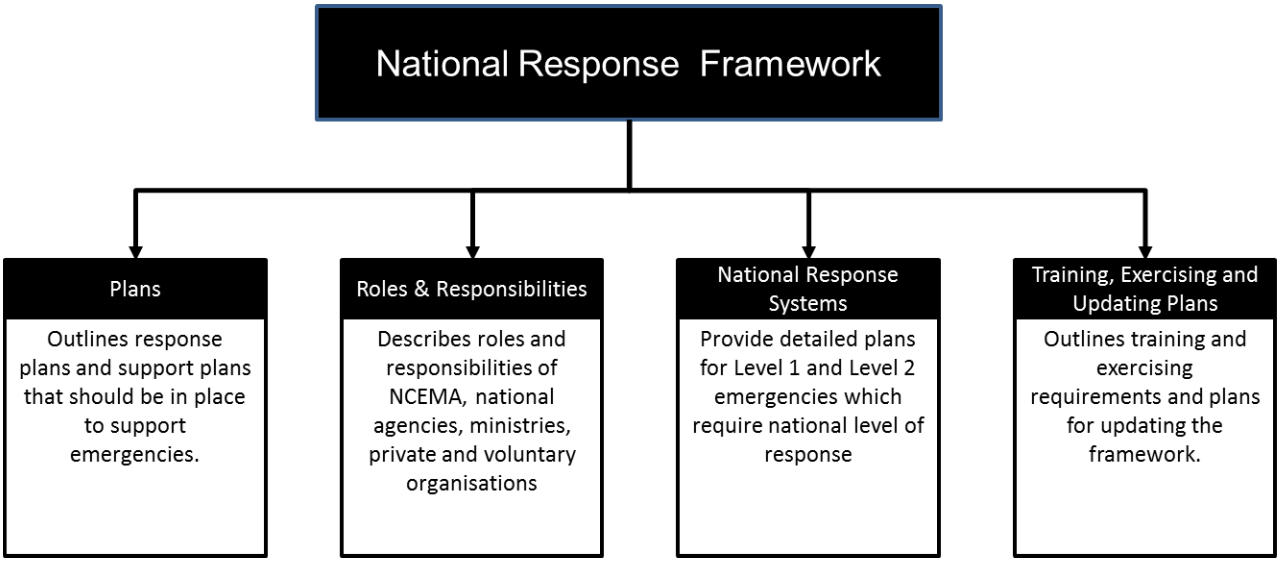


Figure 1.4: Main elements of the UAE National Response Framework (Author)

Although the National Response Framework provides comprehensive guide for dealing with disasters, an initial review of the framework revealed some gaps. For example, it does not include references to any specific emergency preparedness framework or how state-of-the-art technologies could be utilised to provide rapid and integrated responses to emergencies.

1.9. Research Aim, Objectives, and Questions

Given the above context, there is a need to conduct a programme of research to radically transform emergency management systems in the UAE. Technological discoveries bring innovative solutions to emergency management (Yu, Yang, & Li, 2018). For example, technologies such as aerial robotics and big data analytics can make a significant difference to humanitarian relief efforts through greater efficiency and responsiveness (Munawar et al. 2020). Furthermore, modern communication technologies and social media are increasingly playing a critical role in connecting various stakeholders during emergencies. The ability to communicate critical information quickly is an important asset. The initial literature review revealed that no studies had been conducted to identify and integrate emerging technologies in emergency management. Given the increasing importance of Industry 4.0, this research aims to study how Industry 4.0 technologies could be deployed to enhance disaster management in the UAE.

1.9.1. Aim

To design and develop industry 4.0 enabled framework managing large scale emergencies in the UAE.

1.9.2. Objectives

a) Review systems for managing large-scale emergencies in the UAE and provide an overview of historical developments

b) Conduct a series of interviews and a questionnaire survey to gather the current practices, challenges and opportunities in UAE emergency management approaches

c) Investigate the use of Industry 4.0 principles in the context of emergency management

d) Develop an integrated planning framework based on assimilating strategies and technologies such as Industry 4.0

e) Validate and refine the framework work and develop an implementation guide.

Having defined the aims and objectives, it is also essential to state the research questions that this programme of research aims to answer (Mattick, Johnston, & de la Croix, 2018). Three (3) research questions are central to this programme of work.

Research Question 1*: What general enhancements are required to improve UAE National Response Framework?*

Research questions 2*: What roles Industry 4.0 technologies might play in the enhancement of emergency management?*

Research Question 3*: What are the best ways to embed Industry 4.0 technologies in the UAE National Response Framework?*

1.10. Research Approach

This programme of research involved the following stages in achieving the research aim, objectives and answering research questions.

1.10.1. Stage I – Literature review

As reported in Chapter 2, a comprehensive literature review was carried out in order to:

- Develop a deep understanding of topics relating to the proposed research
- Identify areas of prior research and contributions made by others
- Justify the need for the proposed research

1.10.2. Stage II – Research Methodology

Chapter 3 outlines relevant methodological philosophies and approaches deployed to collate and analyse data. Following the guidance provided by the Research Union model (Melnikovas, 2018) steps below were carried out to collate primary data:

- Interviews – a group of interviewees were selected who have close associations with the development and maintenance of the UAE emergency management framework.
- Questionnaire Survey – A questionnaire survey was conducted to strengthen information gathered from the interviews.
- Framework formulation and validation – Finally, secondary data collected from Stage I and the above phases in Stage II, were used to formulate the initial framework for embedding Industry 4.0 in the UAE Emergency Management systems. The framework was then validated, and necessary adjustments were made to produce the final version.

1.11. Structure of the thesis

This thesis consists of five (5) further chapters.

Chapter 2 – Literature review: A research programme of this nature requires a comprehensive review of the literature. This chapter presents current practices, research by others, and technologies. It concludes with the justification for the proposed research.

Chapter 3 – Research Methodology: This chapter outlines how the research onion model was used to generate the research steps required to achieve the objectives of this research programme.

Chapter 4 - Primary Data Collection and Analysis - Interviews and Questionnaire Survey: This chapter presents the use of interviews and the questionnaire to gather insights into the current practices, challenges and opportunities in emergency management systems in the UAE.

Chapter 5 – Design and Development of the I4EM Framework: This chapter includes the process that the researcher went through to generate the framework and its components. Outcomes are presented in a systematic manner with additional evidence where it is vital.

Chapter 6 – Validation and Enhancement of the framework: The primary purpose of this chapter is to provide the details of the validation process, analysis of the collated feedback, and adjustments made to the framework based on the feedback.

Chapter 7 – Conclusions: This final chapter commences with a brief discussion on the rationale, aim and objectives. Then it describes how the research programme has addressed the research questions and states the major contributions to the body of knowledge. It also discusses the limitations of the research and further research opportunities.

Chapter 2: Literature Review

2.1 Introduction

The literature review is an essential and integral part of PhD research. The primary purpose of the literature review is to:

(a) Develop a deep understanding of topics relating to the proposed research

(b) Identify areas of past research and contributions made by others

(c) Justify the need for the proposed research

This chapter begins with definitions, then gradually introduces related subject areas and concludes with evidence to substantiate the main aims of the research programme.

2.2 Disasters and Emergencies - Definitions

As outlined in Chapter 1, since the beginning of mankind, *disasters* have been a common occurrence worldwide. For example, earthquakes and floods have been known natural disasters for centuries. Therefore, the term "disaster" is very accurate.

Another term that is often linked with disaster is *emergency*. The terms "disaster" and "emergency" are often used throughout the literature. For example, Handmer & Dovers (2007) use the two terms interchangeably in their book. Researchers and institutions involved in handling disasters have offered different definitions, for example, the United Nations.

Two examples of definitions are given below.

Alexander (2002) defines disaster as

> *"an exceptional event that exceeds the capacity of normal resources and organization to cope with it. Physical extremes are involved, and the outcome is at least potentially and often actually dangerous, damaging, or lethal."*

Definition from the United Nations states (Pelling et al., 2004).

> *"a serious disruption of the functioning of a society, causing widespread human, material, or environmental losses which exceed the ability of the affected society to cope using its own resources."*

Both definitions refer to large scale events which disrupt lives and livelihoods. Definitions of the term emergency broadly agree that disasters cause emergencies.

(Jan & Robert, 2002). defines emergency as

"the situation arising in the aftermath of a disaster."

Harvey, Baghri & Reed (2002) provides a broader

"Generally, an emergency may be considered to be the result of a man-made and/or natural disaster, whereby there is a serious, often sudden, threat to the health of the affected community which has great difficulty in coping without external assistance."

However, when management aspects are concerned, there are no universally accepted definitions for "disaster management" and "emergency management". Scholars have used these two terms interchangeably (Al-Dahash, Thayaparan, & Kulatunga, 2016).

National agencies which deal with disasters/emergencies have used the term "emergency", for example, Federal Emergency Management Agency (USA) (Bachmann et al., 2015)., National Crisis & Emergency Management Authority (UAE) (Alteneiji , Ahmed, & Saboor, 2021).and Emergency Management Australia (Abrahams, 2001).

Therefore, to maintain consistency across the thesis, the terms "emergency/emergency management" will be used except in places where the use of the term "disaster" cannot be avoided.

2.3 Types of Disasters

As pointed out above, disasters have been known to mankind for centuries. In the first wave of the industrial revolution, natural calamities and wars were the most known disasters. With industrialisation, other types of catastrophes, for example, Bhopal gas leak incident and Chernobyl nuclear accident Shaluf, (2007) presents a very detailed categorisation of disaster types (Figure 2.1)

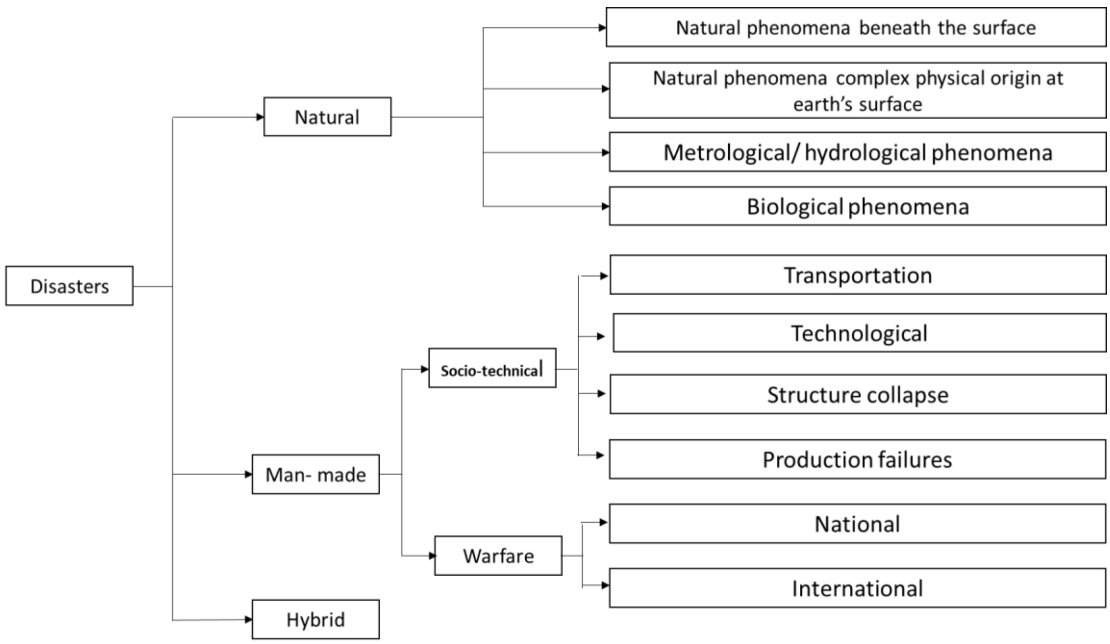


Figure 2.1: Disaster type categories (Shauf, 2007)

In addition to widely known two types, natural and man-made, Shauf (2007) also defines a third type, known as Hybrid disasters. Definitions for these three types are as follows.

(a) Natural - catastrophic events resulting from natural causes such as volcanic eruptions, tornadoes, earthquakes, etc.

(b) Man-made - catastrophic events that result from human decisions/acts such as terrorist attacks and industrial incidents

(c) Hybrid disasters result from both human error and natural forces. For example, landsides (natural) caused by soil erosion due to excessive jungle clearing (man-made)

Shauf (2007) also provides a range of examples for three types. (Table 2.1)

Disaster type	Sub-disaster	Name of disaster
Natural	Natural phenomena beneath the Earth's surface	• Earthquakes • Tsunamis • Volcanic eruptions
	Topographical phenomena	• Landslides • Avalanches
	Meteorological/hydrological phenomena	• Windstorms (cyclones, typhoons, hurricanes) Tornadoes • Hailstorms and snowstorms Sea surges • Floods • Droughts • Heat waves/cold waves
	Biological phenomena	• Infestations (locust swarms, mealy bug) • Epidemics (cholera, dengue, ebola, Covid-19 etc)
	Technological disasters	• Fire • Explosions (munitions explosions, chemical explosions, nuclear explosions, mine explosions) • Leakage • Toxic release • Pollutions (pollution, acid rain, chemical pollution, atmospheric pollution) Structural collapse of physical assets
	Transportation disasters	• Air disasters • Land disasters • Sea disasters
Man-made	Socio-technical/ Public places failures	• Fire • Structural collapse • Crowd stampede
	Socia-technical/ Production failures	• Computer system breakdown • Distribution of defective products
	Warfare/National	• Civil war between armed groups from the same country • Civil strikes • Civil disorder • Bomb threats/terrorist attack
	warfare/International	• War between two armies from different countries

		• Sieges • Blockades
Hybrid	Natural and man-made events	• Floods ravage communities built on known floodplain • Location of residential premises, factories, etc., at the foot of an active volcano, or in an avalanche area Landslides

Table 2.1: Examples of disasters (Shaluf, 2007)

2.4 Growing threats from disasters

The Centre for Research on the Epidemiology of Disasters – CRED, Université Catholique de Louvain, Belgium, maintains a series of databases to record data relating to all categories of disasters from around the world (Guha-Sapir, Hargitt, & Hoyois, 2004). According to their analysis, the number of disasters, particularly natural disasters, has increased at an alarming rate over the last four decades (Pamidimukkala, Kermanshachi, & Karthick, 2020,).

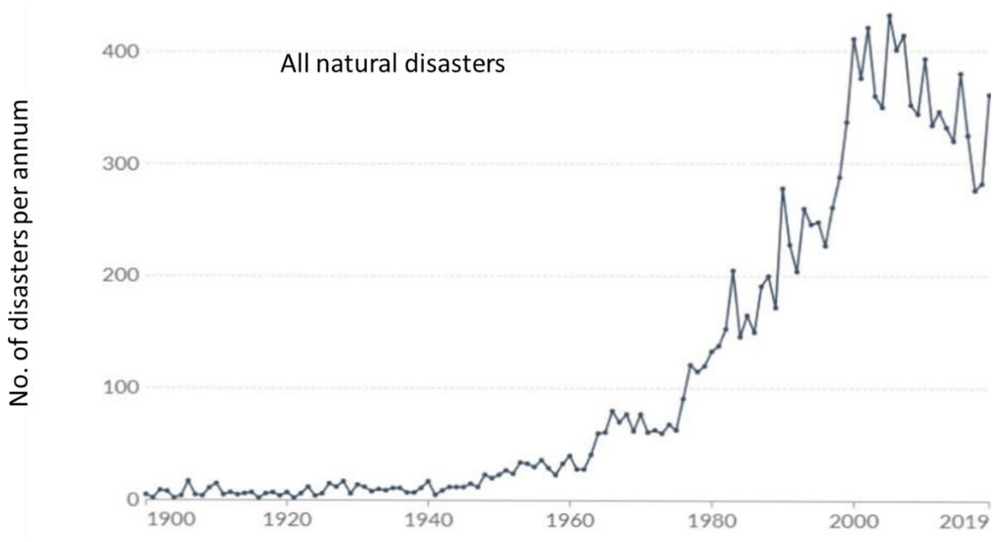


Figure 2.2: The growth of all natural disasters (EMDAT, 2020)

Figure 2.2 shows the rapid growth of the number of natural disasters since the beginning of the last century.

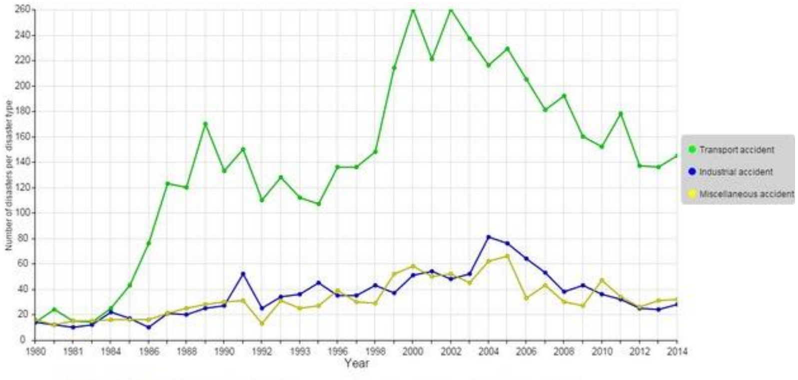


Figure 2.3 The growth man-made disasters (EMDAT, 2020)

As shown in Figure 2.3, the number of man-made disasters appeared to have reached its peak at the beginning of the 21th century. However, some recent large-scale disasters such as the Rohingya refugee crisis (Lewis, 2019). Syria civil war (Van Dam, 2017).and the Venezuelan refugee crisis (O'Neil, 2019). will have reversed this trend.

There are several underlying causes that are driving the rate of disasters up:

(a) Global warming – This is universally acknowledged as the key cause of natural disasters (Miles-Novelo & Anderson, 2019). Human-driven actions such as burning fossil fuels and deforestation are seen as the major contributors. The Intergovernmental Panel on Climate Change (Díaz et al., 2019). has unequivocally stated that human activity is the cause of global warming.

(b) *Rapid expansion of world population* – The world population has increased from 1.6 billion in 1990 to nearly 6 billion over a century (He, Goodkind, & Kowal, 2016). Developing countries are experiencing disproportionately high growth. For example, the population of Africa is expected to double by 2050, to over 2 billion (Bremner, 2012). Unsustainable population growth increases environmental pollution, which has caused climate change (Howat & Stoneham, 2011).

(b) *Rapid industrialisation* – This is seen as a major cause of man-made disasters. Industrial accidents and large-scale spills are some examples (Nguyen et al., 2019).

(c) *Excessive traffic densities* – Global supply chains, urbanisation, and rapid growth in air travel have increased traffic densities hence the heightened risk of traffic-related disasters.

(d) *Climate change* – This is now acknowledged as one of the major reasons for natural disasters.

(e) *Terrorism* – Threats from radicalised groups are ever-increasing. Some recent major atrocities were caused by terrorism.
(f) *Arm conflicts* – Various arm conflicts are raging in some parts of the world and has led to humanitarian crises.

These continually growing threats mean how to manage the consequences of disasters remains a subject of interest for researchers.

2.5 Disasters in the UAE

Although not widely reported internationally, there have been many natural and man-man disasters in the UAE, (Table 2.2) lists some of the major incidents reported in the national/international media.

Disaster type	**Sub-disaster**	**Disasters in the UAE (selected examples)**
Natural	Natural phenomena beneath the Earth's surface	• Masafi earthquake (2002)
	Topographical phenomena	• Masafi earthquake (2002) • Al Tawaian landslides (2006) • Al Dheit Landslides (2019)
	Meteorological/hydrological phenomena	• Al Qurayah floods (1995) • Sharm flood (2009) • Al Ain sandstorms (2019)
	Biological phenomena	• UAE foot and mouth disease found in animals (2001) • Covid-19 (2020)
Man-made	Technological disasters	• Oil spill in the territorial waters of the Emirates (1994 and 1998) • Dubai gas explosion (2019)

	Transportation disasters	• Crash of an American cargo plane on Al Ain highway in (2010) • Crash landing of an Emirates plane which caught fire at Dubai International Airport in (2016)
	Socio-technical/ Public places failures	• Bridge collapse while under construction in Dubai (2007) • Large scale fire at Dubai's famous The Address Hotel in Downtown Dubai (2016)
	Socio-technical/ Production failures	• Rapidly rising Cyberattack attempts
	Warfare/National	• Sharjah worker riots (2008) • Abu Dhabi worker (2020)
	warfare/International	• The liberation of Kuwait in (1991) • The war on ISIS (2014) • "Al-hazem storm " Yemen (2015)

Table 2.2: Reported disasters in the UAE

As can be seen from the table, there have been many large-scale disasters.

2.6 Emerging disaster risks in the UAE

Although the number of fatalities has not been high so far, there are emerging risks that may lead to large-scale loss of life.

(a) Terrorism

Christopher M. Davidson provides a detailed insight into how terrorism cause a major threat to the security of the UAE. Being a strong ally of Western countries, the UAE is seen as a foe by several regional counties. The most threatening regional player seems to be Iran (Davidson, 2007). In the event of a terrorist attack, the number of casualties could be significant as there is a high population density in urban areas.

(b) Geo-politics

The Middle East is a hotbed of geopolitics. The long running hostilities between Israel and Palestine has created many challenging issues for neighbouring countries. Civil war erupted in Syria in 2011 and has been a major conflict in the region with more than 400,000 deaths by early 2020. Closer to home, the on-going civil war in Yemen since 2015 has been a real threat as the UAE was directly involved in the conflict.

(c) Rapidly increasing urban population

Elessawy (2017). explains how the urban population in Dubai alone has increased by 1000% over the last three years. The key factor behind this immense growth is the immigration workforce. The ever-growing development of urban areas, major capital projects and organisation of global events such as Expo 2020 have attracted workers from around the world. Unfortunately, this open approach has also attracted individuals/groups who may undermine civil obedience.

Given the above risk factors, the UAE requires a much more sophisticated approach when managing disasters and emergencies.

2.7 Managing emergencies

To minimise the number of casualties and to reduce the risk of re-occurrence where possible, some forms of an organised approach are required. Historically, how emergencies were dealt with, were most likely to have been reactive i.e. actions taken after the event. This began to change in early 18th century when central governments recognised that their involvement was critical in dealing with major disasters. For example, In 1803, USA Federal Government passed a congressional act to provide financial assistance to a New Hampshire town that had been ravaged by fire (Moss, 2007).This involvement is considered to be the catalyst for the development of the discipline of emergency management.

2.8 Emergency Management Models

Neal (1997) states that studies and discussions on emergency management began in the early 1930s. These studies primarily focused on humanitarian responses and finding ways to improve the effectiveness of responding to disasters (Lewis, O'Keefe, & Westgate, 1976). With a dramatic increase in disasters in 1970 which caused a great economic impact, scholars began to develop more formal approaches to emergency management (Wisner, 2004). The formal approaches have been labelled as either “emergency management cycles” or “emergency management models”. To maintain consistency across the thesis, “emergency management models” are used hereafter.

Kelly (1998), elegantly explains the benefits of models for emergency management.

(a) *Focusing on critical elements* - Emergencies by nature are complex events. Models help to differentiate critical elements and noise.

(b) *Developing better insights* – Comparing the current situation and the theoretical model helps to understand the current situation better.

(c) Quantifying impacts - Models also help to quantify disaster effects, thereby identifying the required data for quantifying.

(d) *Sharing the understanding* – Models enable all stakeholders to develop a common understanding of the emergency.

The literature review identified four (4) key phases that have been regularly used by emergency management model developers (Figure 2.4).

Mitigation Phase *– identifies possible precautionary approaches that can be implemented to avoid emergencies or minimise their impact.*

Preparedness Phase *– Formulating plans and actions required to deal with emergencies.*

Response Phase *– Deploying plans/actions developed in the preparedness phase and/or any other necessary actions to deal with emergencies.*

Recovery phase *– Implementing interventions required to recover from the emergency i.e. supporting communities to reach some form of normality.*

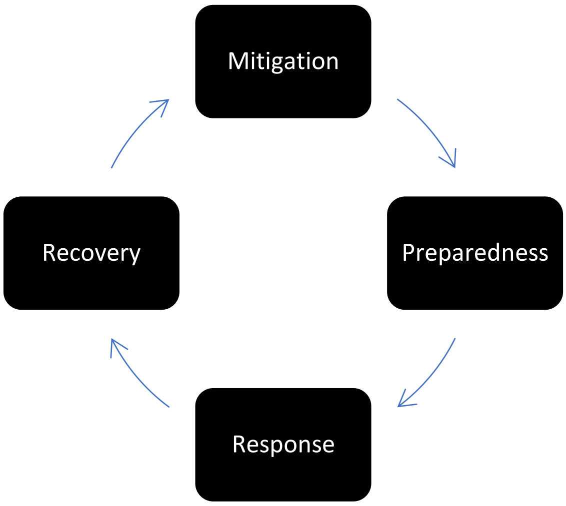


Figure 2.4: Common phases of emergency management models

In the following, variations of emergency management models are presented in chronological orer.

2.8.1 Traditional Model (1998)

This model proposed by DPLG (1998), consists of two stages, *pre-Disaster risk-reduction phase* and *post-disaster recovery stage*. The first stage includes two of the commonly used phases, *Mitigation* and *Preparedness, and* in addition, *Prevention* has been added as another phase. The second stage too includes two commonly known phases *Response and Recovery* and another phase known *as Development.*

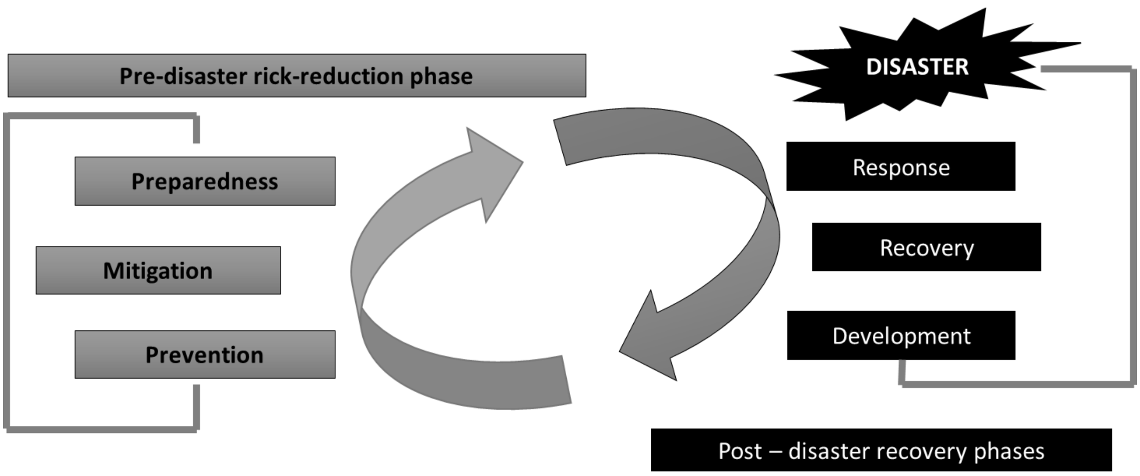


Figure 2.5: Traditional Model

2.8.2 Expand and Contract Model (1998)

DPLG (1998) also proposes the expand-contract model as an alternative to its traditional model. The key difference is that management of emergencies is considered a continuous process. Authors argue that emergencies are managed in a set of parallel activities rather than a sequence of activities. This means that different strands continue side by side, expanding or contracting as needed. For example, after a flood, “relief and responses” and “recovery and rehabilitation” strands start immediately after the event. However, when “relief and responses” *expand* to cope with immediate effects “recovery and rehabilitation” play a minor role. As time goes by, “recovery and rehabilitation” expands and “relief and responses” contracts.

Figure 2.6: Expand and Contract Model

2.8.3 Circular Model of Emergencies (1998)

Kelly (1998) presents a disaster management model with eight phases. The standard Recovery Phase (described above) has been expanded to include Rehabilitation, Reconstruction and Development. Kelly (1998) argues that the linear model of disasters (Figure 2.7) is not realistic. When a disaster strikes, many phases become active simultaneously. For example, both Recovery and Mitigation are likely to take place simultaneously following a disaster. Kellly (1998) categorises this as a non-liner model, however, the model representation looks more linear.

Figure 2.7: Kelly's Circular Model (Kelly, 1998)

2.8.4 Crunch and Release Model (2000)

ADPC provides a framework for understanding the causes of a disaster. The fundamental principle in this model is that a disaster occurs only when a disaster affects vulnerable people.

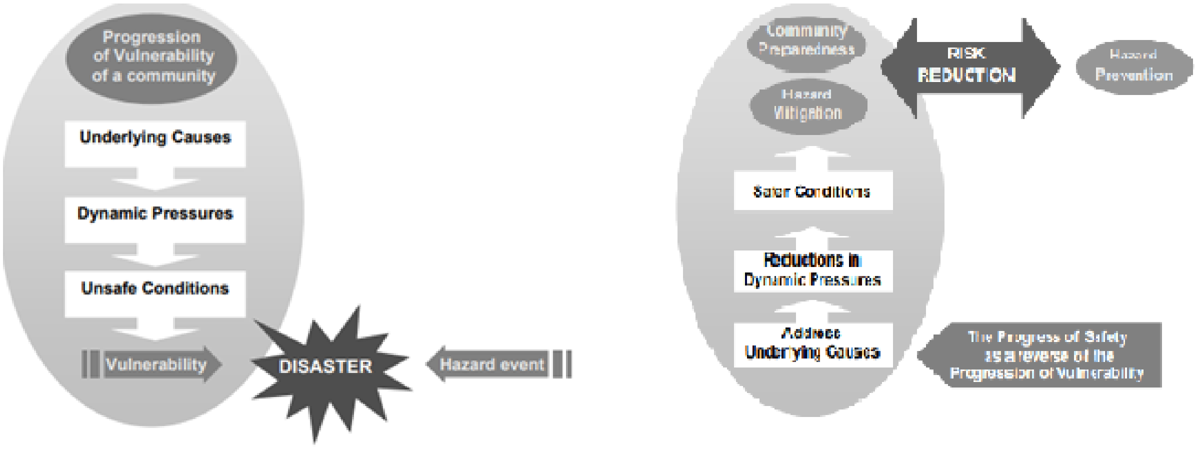


Figure 2.8: Crunch and Release Model

2.8.5 Weichselgartner Model (2001)

Weichselgartner (2001) argues that integration of vulnerability and risk assessment should be an integral part of emergency management model. The overall objective of this model is to assess the possible damages from a disaster and plan future actions to reduce possible damages.

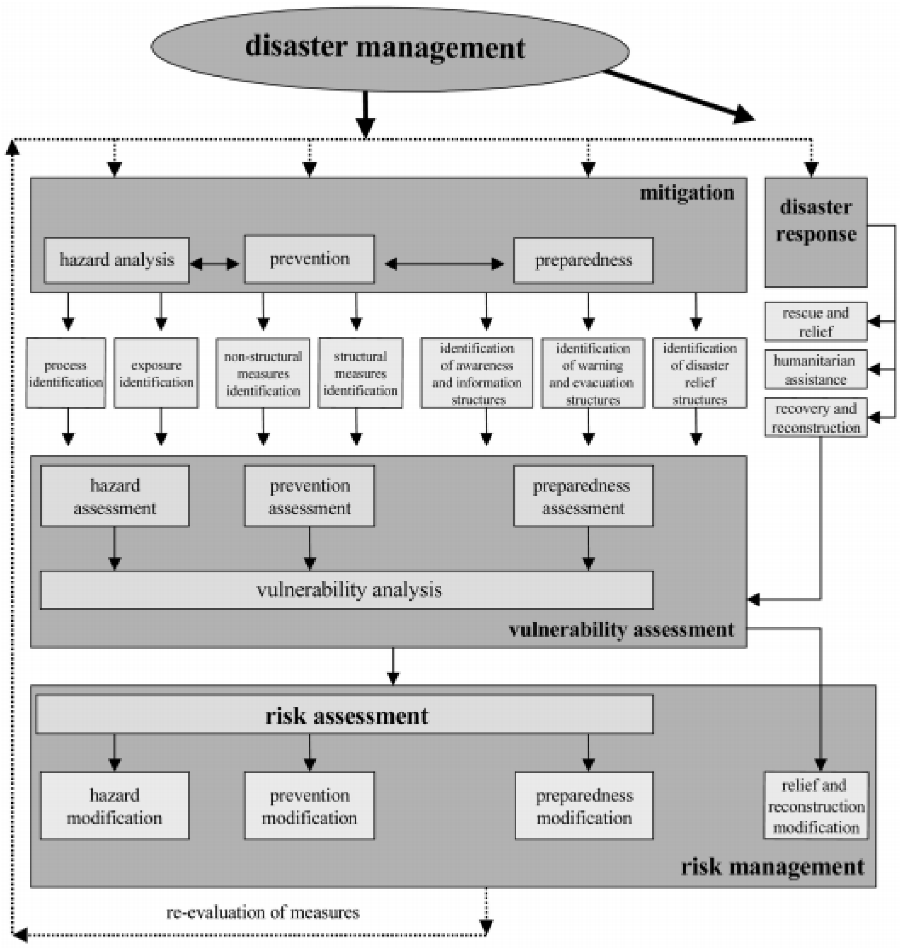


Figure 2.9: Weichselgartner Model (2001)

2.8.6 Manitoba model (2002)

Manitoba Health Disaster Management Group presents an extended model which has six (6) phases. This model stipulates that Mitigation and Preparedness phases take place in parallel. Hazard Management and Risk Management are integral elements of the models

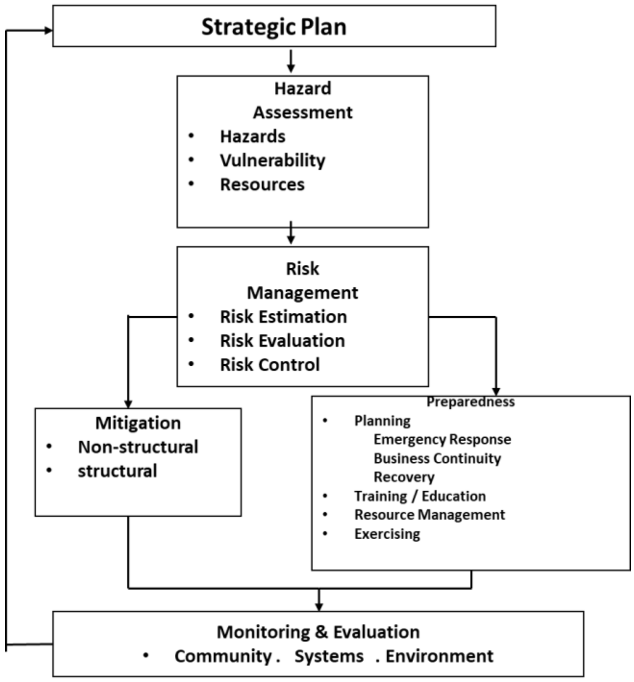


Figure 2.10: Manitoba Model

2.8.7 Kimberly model (2003)

Kimberly (2003) reorganises the standard 4 Phase model, as shown in (Figure 2.11), to emphasise Response as the most important phase. Mitigation and Preparedness phases are show in the base to portray that they are the driving force behind a successful response.

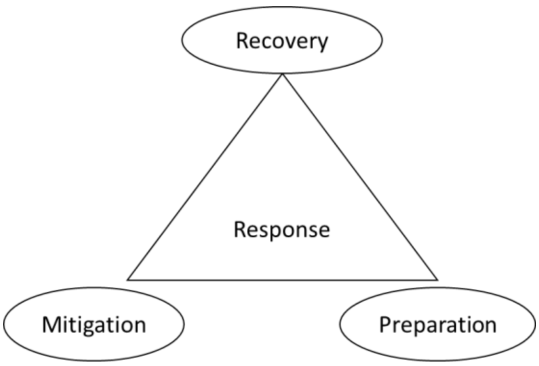


Figure 2.11: Kimberly model (2003)

2.8.8 Tuscaloosa model (2004)

Tuscaloosa County Emergency Management Cycle (Hampel 2004) is identical to the stands 4-phase model. Although it is not shown in the model representation, Hampel (2004) argues that mitigation is the most important phase. Therefore, in this model, mitigation is considered as the first phase.

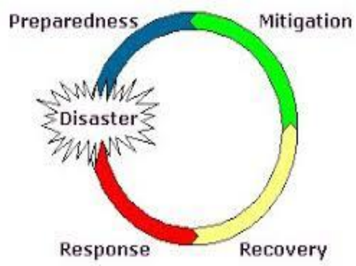


Figure 2.12: Tuscaloosa Model

2.8.9 Comprehensive Conceptual Model (2006)

Asghar et al (2006), present a very comprehensive of emergency management model involving five (5) components which are divided into various sub-activities. This model has been developed by identifying the limitations of other models.

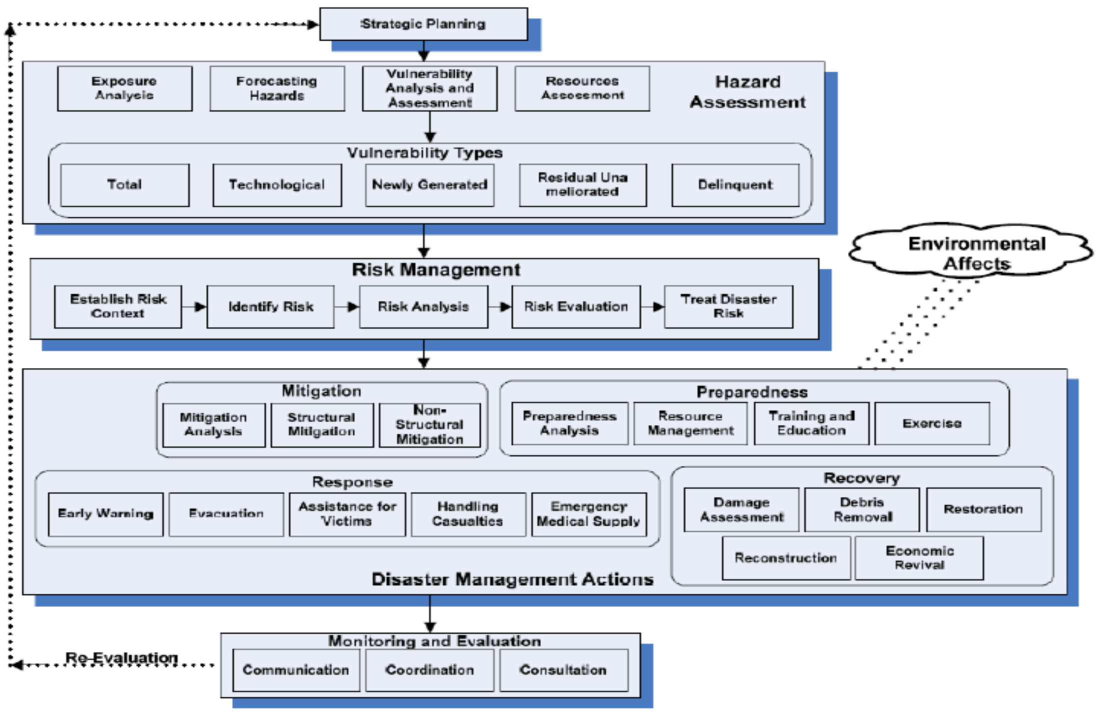


Figure 2.13 : Comprehensive Conceptual Model

2.8.10 Multi-layer Quillnan model (2009)

Although the purpose of this model is different to the models described above, it has been included in reviews of emergency management models by several authors (Quillinan et al., 2009, Penserini, et al.,2009). This is a highly sophisticated agent-based simulation model developed for crisis management in the Netherlands.. There are three layers in this model:

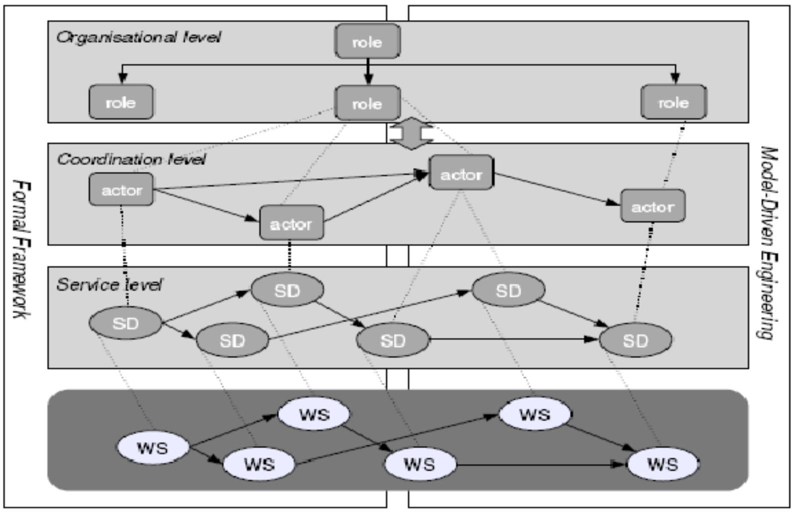


Figure 2.14: Multi-layer Quillnan model (2009)

(a) Organisational Role Dependency

This shows the relationships between various agencies involved in handling disasters.

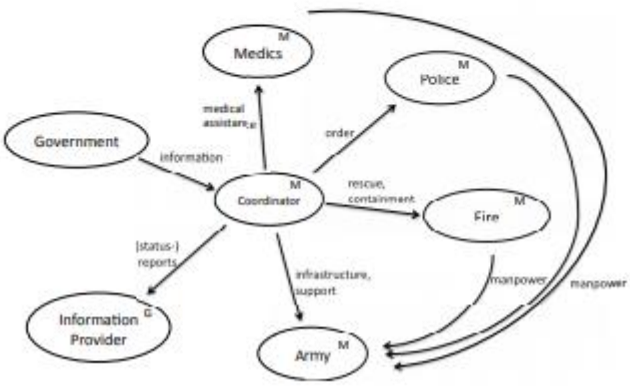


Figure 2.15: Organisationnel Rôle Dependancy

(b) Organisational Interaction Pattern

This shows the interactions between organisations.

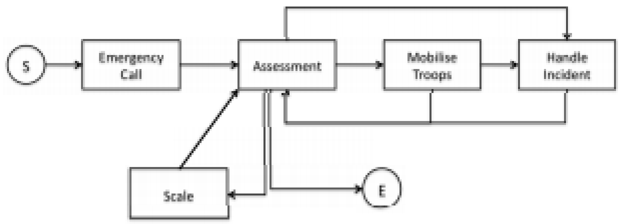


Figure 2.16: Organisational Interaction Pattern

(c) Landmark patterns

This shows how specific interactions should be achieved.

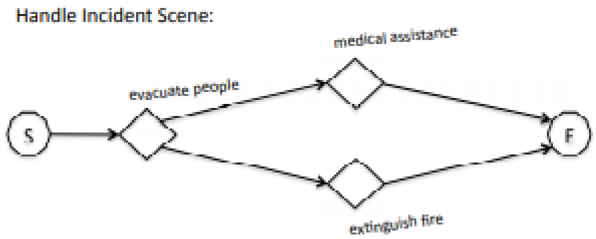


Figure 2.17: Landmark Patterns

2.9 Review of emergency management models

Asghar, Alahakoon, & Churilov, (2006) provides definitions for three categories of emergency management model.

Category 1: logical Models – these models include basic phases of emergency management models i.e., mitigation, preparedness, response and recovery.

Category 2: Integrated Models - Integrated models extend logical models by appending other phases such as strategic planning and monitoring.

Category 3: Cause Models – These models identify the causes of disasters.

Model	Category	Type of Disaster	Serial/Parallel Phases	Remarks
Traditional Model (1998)	Category 1	Any	Serial and Parallel	It consists of two major phases "Risk Reduction" and "Recovery". Each phase has three major activities which may take place in parallel.
Expand and Contract Model (1998)	Category 1	Any	Parallel	The key feature of this model is that all phases take place in parallel, with a varying degree of importance/effort
Circular Model of Emergencies (1998)	Category 1	Any	Serial and parallel	The model aims to highlight the non-linear nature of emergency events. It also includes a higher number of phases.
Crunch and Release Model (2000)	Category 3	Natural	Serial	The key aspect of the model is that the disaster happened when vulnerable communities experience a hazard. Focus is on reducing causes of vulnerabilities.
Weichselgartner Model (2001)	Category 2	Any	Serial and Parallel	An extended model which includes

				vulnerability analysis and risk assessment.
Manitoba Model (2002)	Category 2	Healthcare	Serial and Parallel	Hazard Management and Risk Management are integral elements of the model.
Kimberly model (2003)	Category 1	Healthcare	Serial	This model emphasises the importance of the "Response" phase.
Tuscaloosa model (2004)	Category 1	Any	Serial	Although not shown visually, the models emphasis was on the "mitigation" phase.
Comprehensive Conceptual Model (2006)	Category 2	Any	Serial and Parallel	This can be considered as an extended version of Weichselgartner Model. The "Monitoring and Evaluation "phase has been added.
Multi-layer Quillnan model (2009)	Category 2	Any	Serial and Parallel	Agent-based simulation model to study crisis management scenarios.

Table 2.3: Comparison of models (Author)

Key conclusions from the above review are:

(a) With the exception of the "Crunch and Release Model" and "Multi-layer Quillnan Model", all models have used four standards phases in their models.

(b) None of the models highlight the importance of "knowledge management" explicitly. Knowledge gathered from emergency management episodes are critically valuable in the *continuous improvement* of emergency management cycles. This aspect need to be considered when the framework is developed.

2.10 Technologies in Emergency Management

In March 2011, a strong tsunami triggered by a powerful earthquake hit Japan, resulting in severe damage to the Fukushima Daiichi nuclear plant (Yabe et al., 2014). Given the amount of dangerous nuclear material released, a full evacuation of the area began immediately. To safeguard relief workers and to evaluate the damage caused by the explosion, emergency services extensively used drones. This is an excellent example of how modern technology is deployed to assist emergency management efforts. Bomb Disposal Robots are another good example of using technology in emergencies. Drones and robots are well-known technologies as they often appear in the media when dealing with emergencies.

The term technology associates with a wide range of application areas, for example, medical technology, business technology and software technology etc. This literature review identified three major categories of technologies used in emergency management.

(a) Information and Communication Technologies (ICT) – these collect, analyse and distribute information required to deal with emergencies.

(b) Knowledge Management – Managing and utilising the knowledge gathered from emergency management episodes.

(c) Robotic Technologies –Robotic based devices used to support emergency management efforts.

2.11 Information & Communication Technologies (ICT)

Timely and accurate information is a key asset in emergency management. It is an absolute necessity that all stakeholders have access to relevant information to enable them to take the appropriate actions to deal with disasters. The first wave of applications focused on developing Disaster Information Management Systems. In recent years, social media, which is considered to be the amalgamation of ICT and social interactions, began to play a significant role in emergency situations. In the following, the development of Disaster Management Information Systems and the use of Social Media technologies are discussed.

2.11.1 Disaster Information Management Systems (DIMS)

The development of the first information system for emergency management goes back to the early 70s. In 1971, Dr Murray Turoff, employed at U.S. Office of Emergency Preparedness, designed and developed the Emergency Management Information Systems and Reference Index (EMISARI), which is considered to be the first multi-machine chat system. EMISARI was used in several emergency management situations (Turoff, Chumer, de Walle, & Yao, 2004).

In 1992, a technical cooperation project in Latin America and the Caribbean, code named SUMA (Hardcastle & Chua, 1998) was developed to share information relating to incoming relief goods. This was a very specific application of information systems in emergency management. Lakovou & Douligeris,(2001).presents the design and development of another bespoke system, IMASH, an information management system for emergencies caused by hurricanes**.** Ariyabandu (2009) reports the development of an integrated system, “Sahana” in Sri Lanka, after the devastation caused by the 2004 tsunami in the Indian Ocean. A unique feature of this system was its ability to interface with Geographical Information Systems (GIS).

Away from the development of bespoke software systems, Albayrak (2006),presents a framework for the diffusion of Disaster Management Information Systems in emergency management. It outlines how different types of management information systems may be deployed in emergency management cycles.

Lettieri, Masella, & Radaelli, (2009) report the result of investigations into the use of information technologies in emergency management. It is one of the four themes used in their systematic literature review relating to disaster management. Within this context, the authors conclude that there are three principal roles for data/information in disaster management.

(a) understanding of hazards and disasters
(b) decision making
(c) signalling and communication

Lettieri, Masella, & Radaelli, (2009). also identified largely investigated technologies and less investigated technologies by that time.

Largely investigated technologies	**Less investigated technologies**
Geographical information system Relational data base management system Analysis techniques; and Real-time communication systems	Satellites (information) Ground sensors Specific decision support system (DSS).

Table 2.4: Largely and less investigated technologies

Turoff, Chumer, de Walle, & Yao, (2004).states that the September 11 attack, which killed more than 3,000 people, accelerated the further development of Disaster Information Management Systems. However, Dorasamy & Raman, (2011), argues that it has not been possible to develop a generic DMIS as different countries are developing their own systems.

Rafi, Aziz, & Lodi (2018) provide an extensive analysis of the development of DIMS in various countries. This analysis reveals that most of DIMS developments have focused on the Response and Recovery phases of the emergency management cycle; only a few addressed the information management requirements of the mitigation phase. It also presents a generic structure of DIMS by assimilating features from a range of DIMS developments.

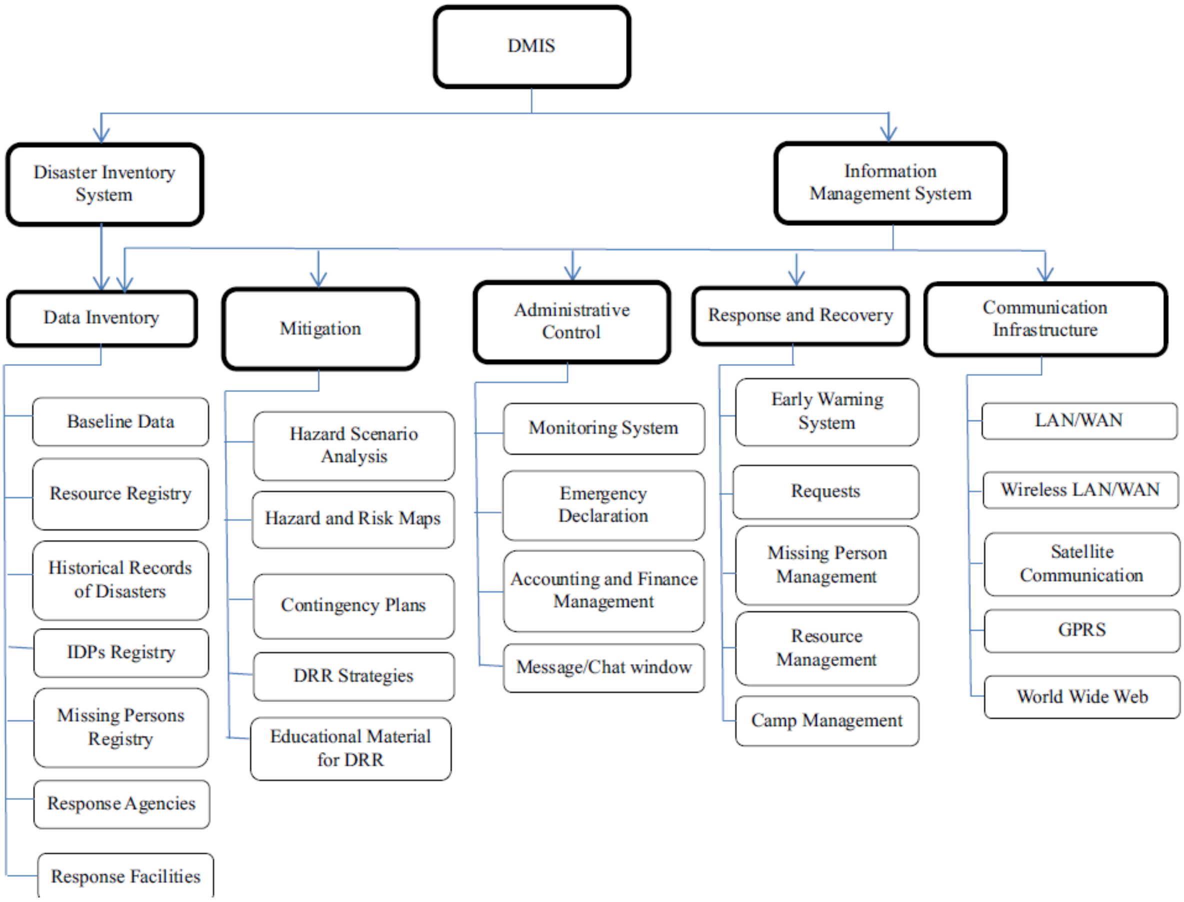


Figure 2.18: Components of a Disaster Management Information Systems (Rafi, Aziz, & Lodi (2018)

Data Inventory encompasses different types of data required and other modules related to the functional areas. Rafi (2017) also presents a generic model of information flows in DIMS.

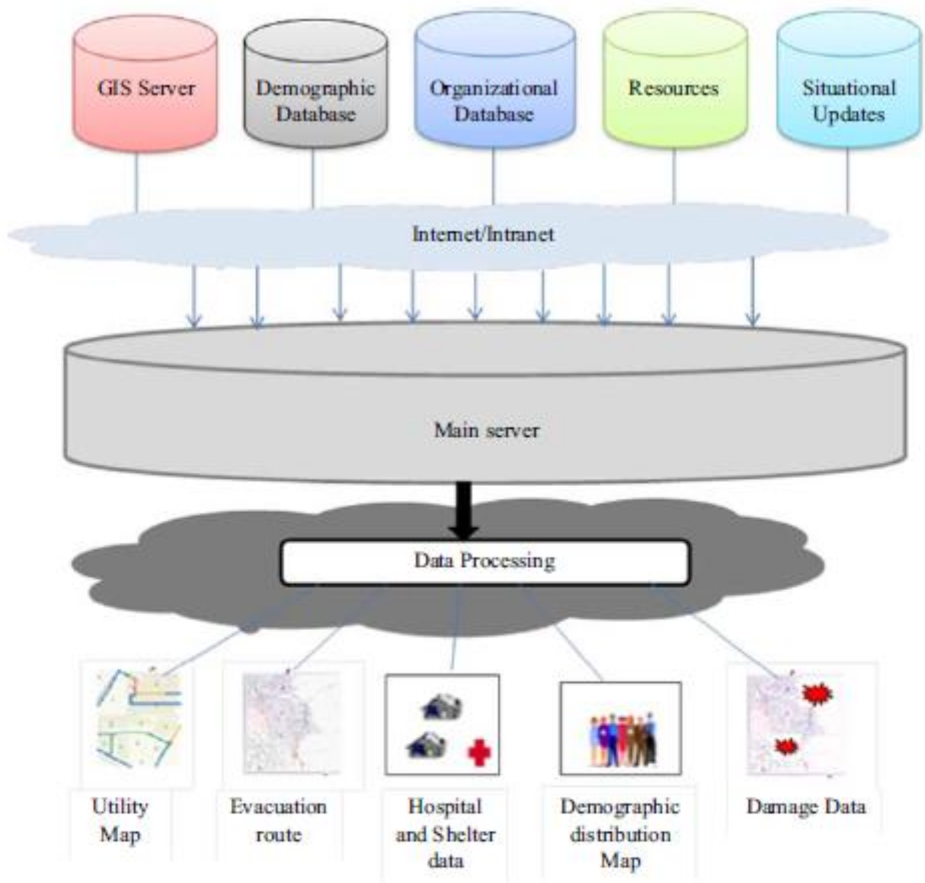


Figure 2.19: Layers of Disaster Information Management Systems

Figure 2.19 depicts how core data (top layer, databases) is synthesised to produce Information (bottom layer) required to deal with emergencies.

2.11.2 Social Media Technologies

Social media, which is the amalgamation ICT and social interactions, has rapidly become an integral part of society. Although the primary use of social media is to connect and share information between individuals, it is now widely used for other purposes, for example, marketing (Ismail, Nguyen, & Melewar, 2018). Given that it is a powerful medium for sharing information quickly and efficiently, social media technologies have been used in emergency management situations (Elbanna, Bunker, Levine, & Sleigh, 2019).

Several publications (Sandvik, et al., 2014) acknowledge that the major use of social media in emergencies first took place during the aftermath of 2010 Haiti earthquake. The US Department of State - Humanitarian Information Unit describes it as groundbreaking in the disaster information management landscape.

"New information and communication technologies, information providers, and international communities of interest emerged during the Haiti earthquake response that will forever change how humanitarian information is collected, shared, and managed. Humanitarian responders used social networking media, mobile phone text messaging, open-source software applications, and commercial satellite imagery more than ever before".

This impetus seems to have instigated the development of formal approaches in using social media technologies in emergency management. For example, a year later, Ahamed (2011) made an assessment of the functional needs of social media centred communication systems with the view to developing framework. As shown in Figure 2.20, the proposed framework depicts how communication between various stakeholders could be improved using popular social media tools.

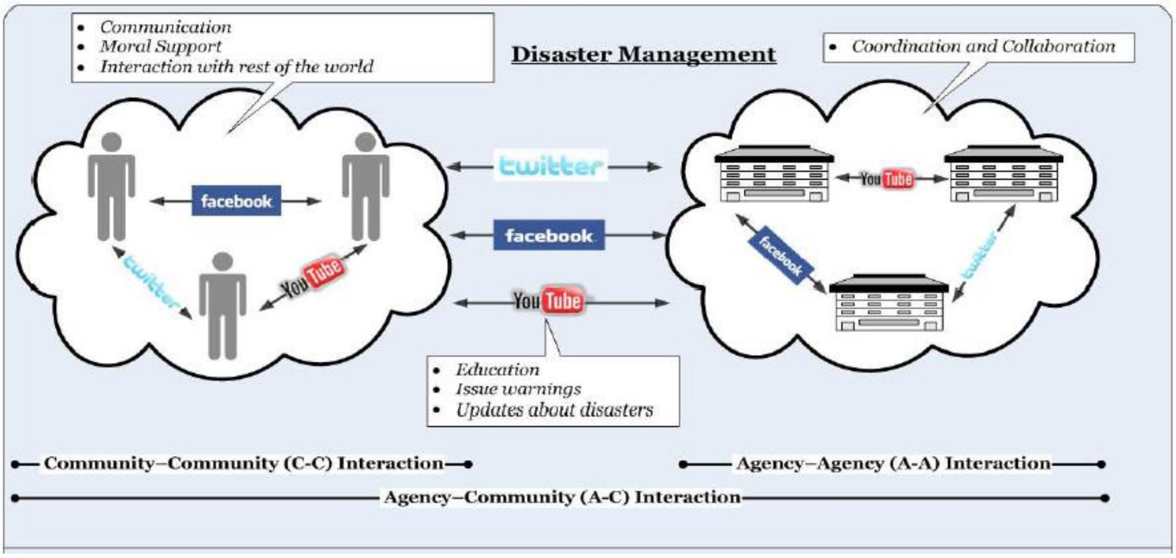


Figure 2.20: The functional needs of social media centred communication systems (Ahamed,2011)

In 2013, Center for Security Studies, Swiss Federal Institute of Technology (Zurich) conducted a study on the use of social media and presented several examples where social media technologies had been successfully deployed. However, despite the many benefits identified, authors insist that a robust social media strategy is required to avoid disseminating premature or inaccurate information.

On their study using ICT and social media in building societal resilience in emergencies, Pitrėnaitė-Žilėnienė (2014) et al., mapped the use of ICT/social media to the four phases of the emergency management Cycle (Figure 2.21).. They also provided an extensive list of research and development work which were taking place at that point.

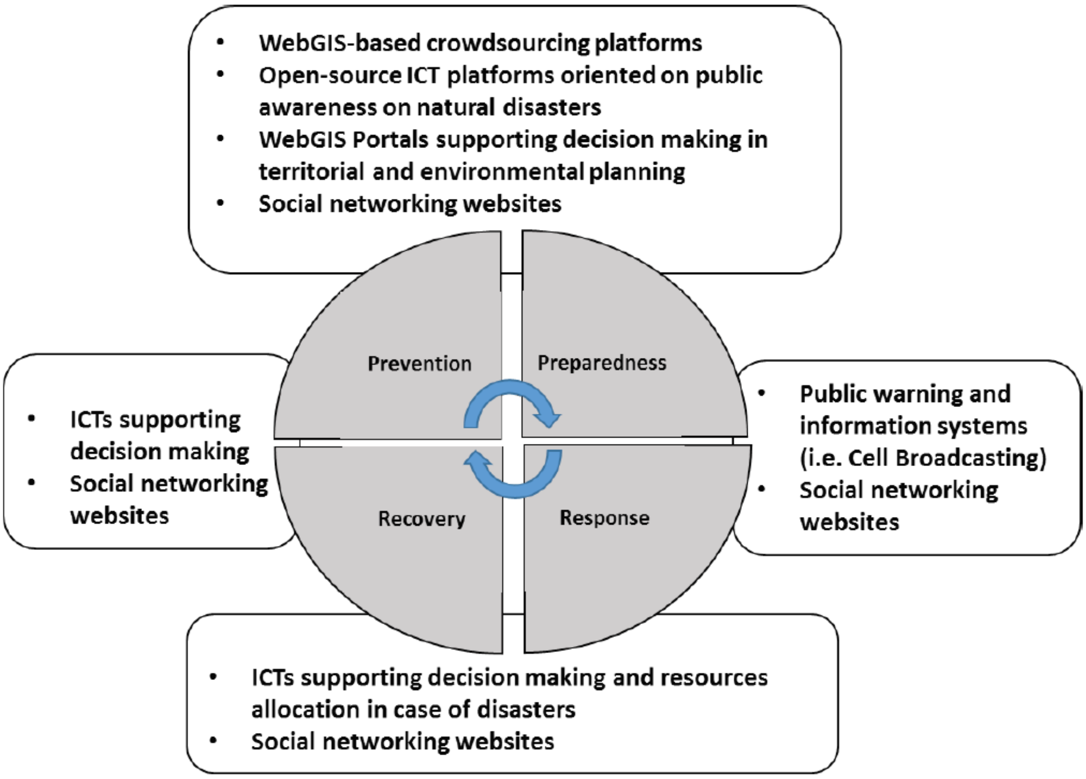


Figure 2.21: Use of ICT/social media to the four phases of emergency management Cycle

Simon et al. (2015) provide a very comprehensive analysis of how social media has been used in emergency management cycles. Their analysis identified four major categories of users of social media tools.

"(a) Innovative – users who improve and adjust social media for their special circumstances
(b) Reactive – users who try to respond and assist the afflicted population using social media tools for the first time
(c) Responsive – emergency responders that use social media tools regularly, but step-up and leverage them during disasters

(d) Proactive – users or emergency organisations that use social media tools to promote preparedness in routine and are able to leverage them“

Simon et al. (2015) conclude that Twitter is the most widely used tool, probably due to its ease of extracting information. Further research is required to assess the effectiveness of social medial tools by first responders and governmental agencies.

Shah et al. (2017) propose a model with two specific components to collect data from stakeholders and social media. The first component, titled as “Disaster Analytic”, enables stakeholders (NGO, government agencies, emergency services and volunteers etc.) to feed information they have for sharing and retrieving relevant information from the systems. The second component, Social Media System Component, which extract, filter and organise data collected through social media sources. Authors also acknowledge that the structured use of social media information in emergency management is relatively new and further work is required to address the challenges of social media data.

Schempp et al. (2019) report the development of a framework to integrate social media and other data sources in disaster relief efforts. By blending data collected from social media interactions and other authoritative sources with mathematical models, this work aimed to optimise the relief distribution. In this study, the authors use data from one disaster only. They acknowledge that further studies are required to improve their framework.

Lovari & Bowen (2019) present the results of their study on the use of social media in disaster communications. They argue that further improvements are required to create robust social media-enabled communication strategies, particularly on how to handle rumours or misinformation.

2.11.3 Geographical Information Systems (GIS)

When dealing with emergencies, many aspects are inherently spatial. Identifying the best available evacuation routes or reconstruction efforts after a disaster are good examples where spatial information is immensely useful.

“A geographic information system (GIS) is a system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data”. The key term here is “Geography”, which means some data is spatial i.e., referenced to a location on the earth. [https://researchguides.library.wisc.edu/GIS]

Cova (1999) presents a comprehensive analysis of how GIS technologies could be deployed in all key phases of emergency management (Figure 2.22)

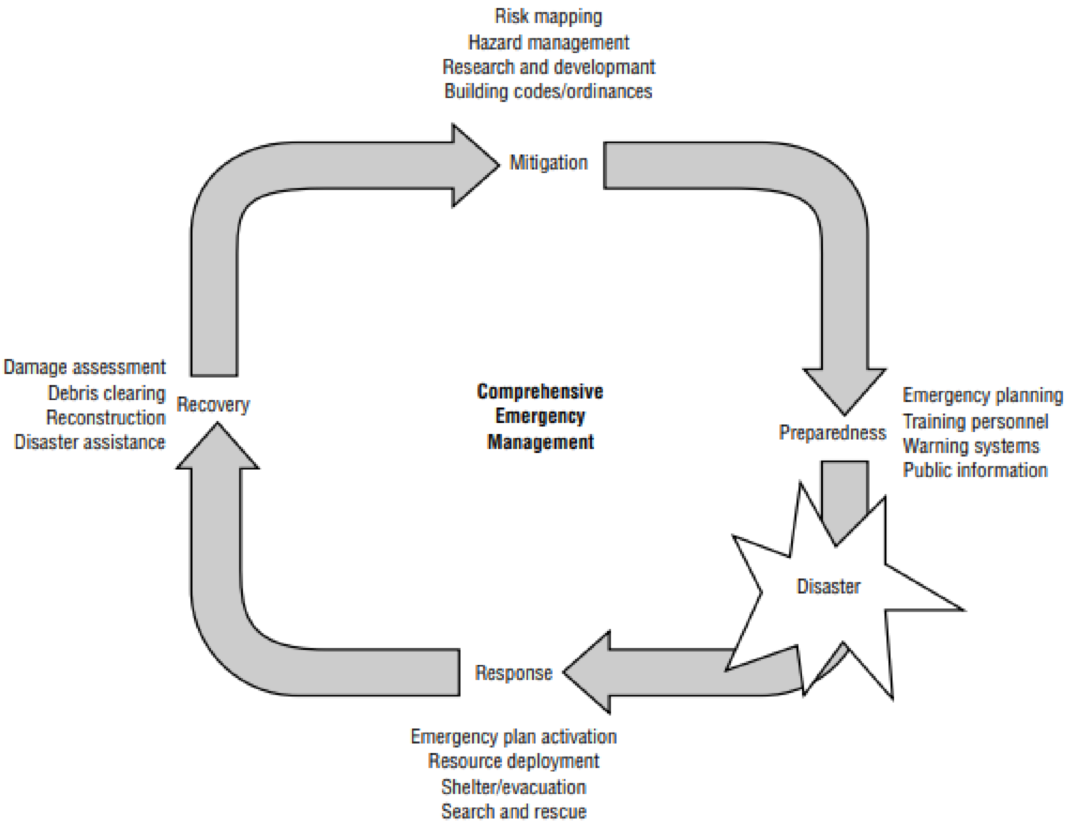


Figure 2.22: Use of GIS in emergency management cycle (Cova ,1999)

GIS is a well-established technology and the use of GIS in emergency management has been an active area of research since the early 90s (Emrich, Cutter, & Weschler, 2011). A book by Tomaszewski (2014) on this subject, Geographic information systems (GIS) for disaster management, has captured historical developments and applications in each phase of the emergency management cycle. The author also outlines potential further developments using emerging technologies at that time, they include:-

(a) Visual Analytics – to enhance the presentation of spatial analysis

(b) Big Data - to process large volumes of data in different formats quickly and accurately

(c) Serious Games – to support disaster management training.

In the following, some recent research and analysis, particularly relating to emergency management, are presented.

Milenković and Kekić, (2016). also provides a range of examples where GIS has been successfully deployed in all four phases of the emergency management cycle. The authors highlight some of the challenges in keeping geographical information up-to-date, specifically after a disaster. They argue that appropriate communications protocols should be in place to ensure that key GIS data is up-to-date in order to accurately reflect reconstruction efforts. The importance of linking GIS with mobile applications has also been highlighted.

Abdella (2016) presents a comprehensive analysis of using GIS in urban emergency management. This study has identified further enhancements required to improve the use of GIS. Among them are:-

(a) Extensive spatial analytical requirements to deal with urban settings

(b) Interoperability of information systems framework

(c) Limited visibility of patient data when dealing with health-related emergencies.

(d) Need for new methodologies for investigation, representation and integration to support urban emergency management.

There is a plethora of research studies on the technological aspects of GIS. Given that this study focuses on the application of GIS, they are not reported here.

2.11.4 Conclusions – Information and Communication Technologies in Emergency Management

Effective management of emergencies requires accurate and timely information. The above studies have clearly demonstrated the critical role of information. Given that the development of disaster management information systems commenced back in the early

70s, it is a very mature field. One noticeable conclusion in this literature analysis is that there is no universally accepted system to manage disaster information.

Whilst management information systems continue to play a critical role, the use of social media tools in emergency management is rapidly rising. Literature reports a wide range of applications and some of the challenges in using social media tools. Given their popularity, social media tools must be an integral part of a national emergency management framework. However, a clear and robust social media strategy should be in place to minimise the impact of potentially inappropriate use of social media during emergencies.

2.12 Knowledge Management in Emergency Management

Although no two disasters are identical, experiences and learnings from one disaster can be very useful when dealing with a similar disaster. Those "experiences and learnings" can be used to gradually build a knowledge repository. Thus, knowledge management has been an active area of research in emergency management (Núñez, Penadés, & Canós, 2017, September).

Among various definitions provided by researchers, Davenport, & Prusak (1998) provides a useful definition.

> "`knowledge is a fluid mix of framed experience, contextual information, values and expert insight that provides a framework for evaluating and incorporating new experiences and information."

This definition can be easily linked to the needs of knowledge management in emergency management.

Framed experience - this refers to case-specific experience. Within the context of this study, it can be linked to experiences/learning from specific emergency management episodes.

Contextual Information – in this case, context is emergency management.
Values – these are integral aspects of stakeholders, such as organisational culture and protocols.
Expert insight – specific views from experts involved in emergency management.

Knowledge Management Systems which are used to organise gathered information, generate knowledge and share knowledge, use different approaches such as Expert Systems, Case-Based Reasoning, Neural Networks and Data Mining (Mamcenko, Kurilovas & Krikun, 2019). Within the context of emergency management, Case-Based Reasoning (CBR) is seen as the most appropriate approach as they enable capturing experiences/leaning from emergency management episodes.

Otim (2006), provides a detailed explanation of CBR can be used from Knowledge Base Systems for emergency management. Figures 2.23 and 2.24 shows the general structure of CBR oriented expert system and its adaptation in emergency management.

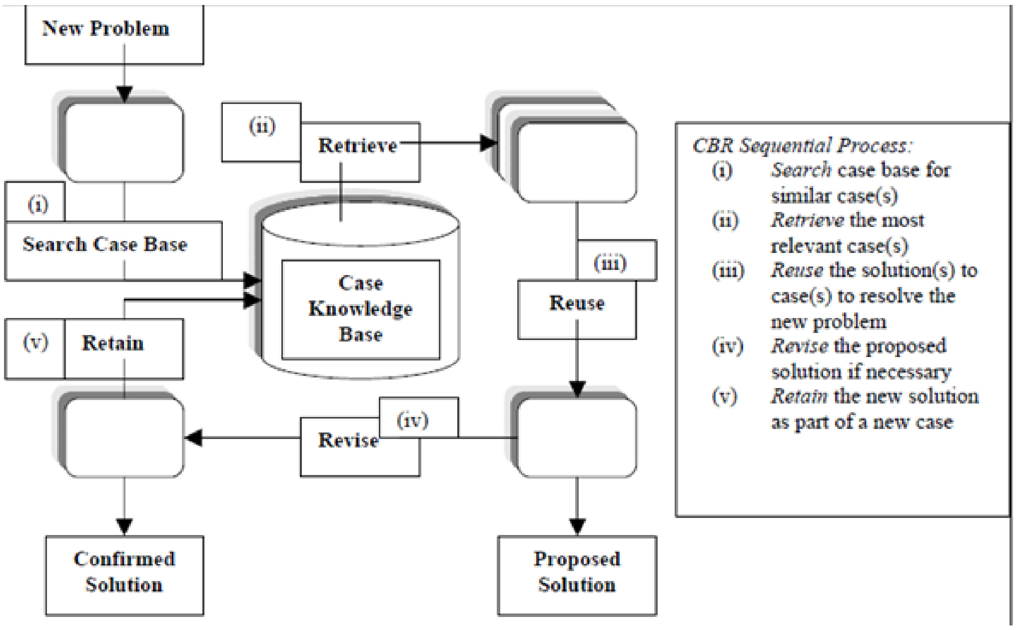


Figure 2.23: Schematic Representation of a CBR Knowledge System (Otim, 2006)

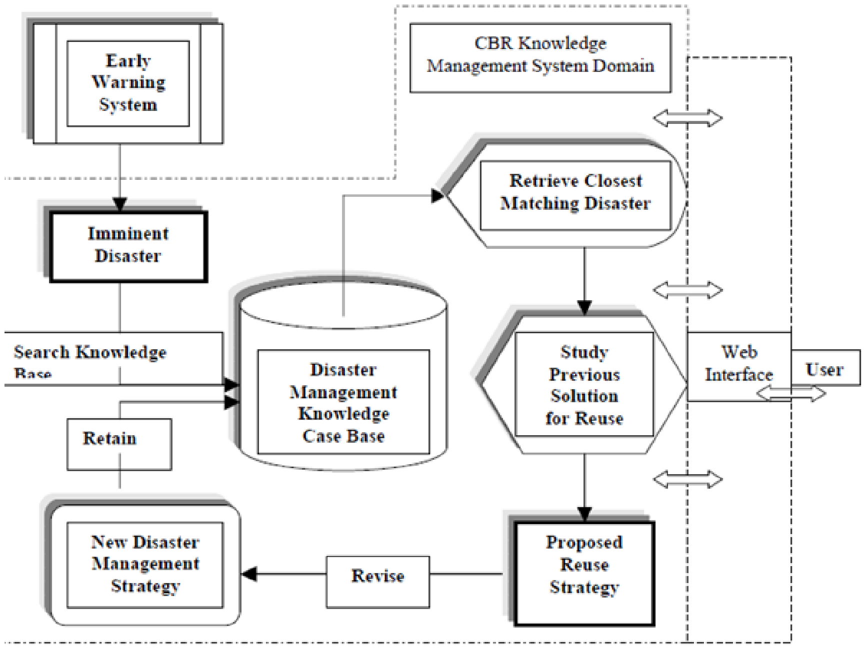


Figure 2.24: Schematic Representation of a CBR Knowledge System for Disaster Management (Otim, 2006)

Triki et al. (2013) present the development of CBR based knowledge management system by using “process mining” technologies. The system has capabilities to assimilate best practices and provide recommendations based on experiences from previous emergencies.

Dorasamy et al. (2012) provides an exhaustive review of work carried out in relation to knowledge management in emergency Management cycles. From a review of 51 papers published between 1990 and 2010, authors conclude that:

(a) there is a need to streamline terminologies used in relation to knowledge management studies in emergency management.

(b) More work needs to be done to understand whether knowledge management systems in emergency information management shares the same goals as Emergency Management Information systems.

(c) Only three papers out of 51 publications, refers to action research in this area.

(d) Further empirical work is required to understand the determinants of knowledge management success factors.

Badpa et al. (2013) presents a conceptual model which aims to enhance the capabilities of a knowledge-based system by RFID technology. Authors argued that RFID networks can be used to gather information from pre-emergency and post emergency scenarios. Badpa (2013) argues that there is a need to have a comprehensive emergency management model in which knowledge management should be an integral element.

Pribadi et.al., (2021) report the need for a comprehensive knowledge management system to enhance infrastructure resilience in Indonesia. Authors argue that lessons learned from five (5) major earthquakes have not been effectively used due to a lack of a robust knowledge management system. The scarcity of information and knowledge has limited knowledge-based decision making in the planning, development and operation of resilient infrastructure. This study concludes that the impact on infrastructure and lives could be minimised if the lessons learned from previous earthquakes are utilized effectively. Rebotier et.al., (2021) question, "*why does humankind suffer more losses while knowing more and in spite of innumerable existing disaster risk reduction policies?*". Authors argue that there is a gap between a logical requirement to learn from the past while trying to mitigate, if not prevent, disasters. They also argue that the deployment of an effective knowledge management system is the key to minimising this gap. A comprehensive review on emergency decision making for natural disasters conducted by Zhou et. al., (2018) also concludes that knowledge management systems can drastically improve the quality of decision making. With the view to enhance the quality of information generated from knowledge management systems for emergency management, Kovalenko and Velev (2021) propose a methodology to integrate big data analytics in traditional knowledge management systems.

2.12.1 Conclusions - Knowledge Management in Emergency Management

The literature review clearly supports the important role that knowledge management systems can play in emergency management. Case-Based Reasoning Knowledge Systems best serve the needs of managing knowledge in emergency management. It is proposed that the knowledge-based system should be an integral element of the proposed framework.

2.13 Robotics and Autonomous Technologies

Some disasters create environments that may be unsafe for human rescuers. For example, a collapse of a large building due to a gas explosion may make a very perilous environment due to continuing gas leaks and/or unstable structures. In such situations, unmanned devices may be used to search and rescue trapped victims.

2.13.1 Robotic Technologies

Robin Roberson Murphy, Raytheon Professor of Computer Science and Engineering at Texas A&M University (USA) is recognised as the founder of rescue robotics technologies (Murphy, 2004).Following the Oklahoma city bombing in 1995, one of her students suggested that small rescue robots be developed for future disasters. This small step paved the way to developing a series of search and rescue robots. It is reported that the first use of a search and rescue robot was in September 2001, during the aftermath of September 11 attacks (Madhavan, Prestes, & Marques, 2015). The review of the literature revealed that since then, the development of underlying technologies has accelerated, and R&D initiatives have very much focused on the technological development of rescue and search robots. Below, a few examples are presented to show the spectrum of research that has taken place.

Penders at el. (2007) discuss the development of a swarm of autonomous robots for emergencies. These robots, equipped with an array of sensors and mobile communication devices, are capable of warning of toxic gases and other dangerous environments, enabling human rescuers to take precautionary actions before entering an affected area. Tan & Zheng, (2013) discuss further advances in research efforts to improve the use of swarm robots.

DeDonato et. al (2014) reports the development of a robot for the DARPA (Defense Advanced Research Projects Agency) Robotics Challenge. This robot is specifically designed for disaster response. One key feature of this development was integrating “Human-in-the-loop Control” to improve the interactions between human and robotic rescuers.

Robinette, Howard, & Wagner (2015) argues that in some instances, humans over-trust robots potentially leading to disastrous effects. To assess human behaviour, the team set up an emergency evacuation scenario using artificial smoke, and fire alarms and robots were deployed to navigate people to safe locations. To the surprise of the research team, all human participants followed the robots even when it was clear that the navigations provided to the robots were not accurate. In one specific experiment, the researchers observed that humans followed robots into a dark room (not a safe location) even when there were many safe exits. Researchers argue that further work is required to identify why human over-trust robots even when there are secure and safe options available.

Savour et al.(2017) present their study on the crowd evaluation simulation models to enhance the behaviour of autonomous robots. They argue that one of the key challenges that robotic search and rescue missions face is changing crowd behaviours during evacuations. They demonstrate how different simulation models could be used to improve the performance of autonomous robots. This publication also lists major crowd simulation software.

Buettner & Baumgartl (2019) describe developing a "deep learning-based escape route recognition module" for autonomous robots in crisis and emergencies. The purpose of this research was to enhance the intelligence of the robot. They conclude that by capturing more environmental data, it is possible to improve the accuracy of the unit and, thereby the performance of the robot.

Scanlan et al.,(2017) outline the trends in using robotic devices in emergency management and further research required to improve underlying technologies. It has identified five (5) areas for further research.

Autonomy – Currently, robotic devices require a high degree of human supervision. Further work is required to make them much more independent devices, for example using Artificial Intelligence.
Sensors – Development of new sensor technologies to detect changes in the environment.
Communications – Improving communication between devices.
Energy Storage and management – Development of new technologies to increase devise deployment time.

2.13.2 Unmanned Aerial Vehicles (UAVs)

Natalizio et al (2017) provides an elegant introduction to how Unmanned Aerial Vehicles (UAV), commonly known as Drones, be used in emergency management cycles. It also lists three major application areas for UAVs in emergency management.

"(a) Pre-disaster preparedness—UAVs have capabilities to survey related events that precede the disaster, offer static WSN-based threshold sensing, and set up an EWS.
(b) Disaster assessment—UAVs provide situational awareness during the disaster in real time and complete damage studies for logistical planning.
(c) Disaster response and recovery— UAVs support SAR missions, forming the communications backbone, and they provide insurance-related field surveys."

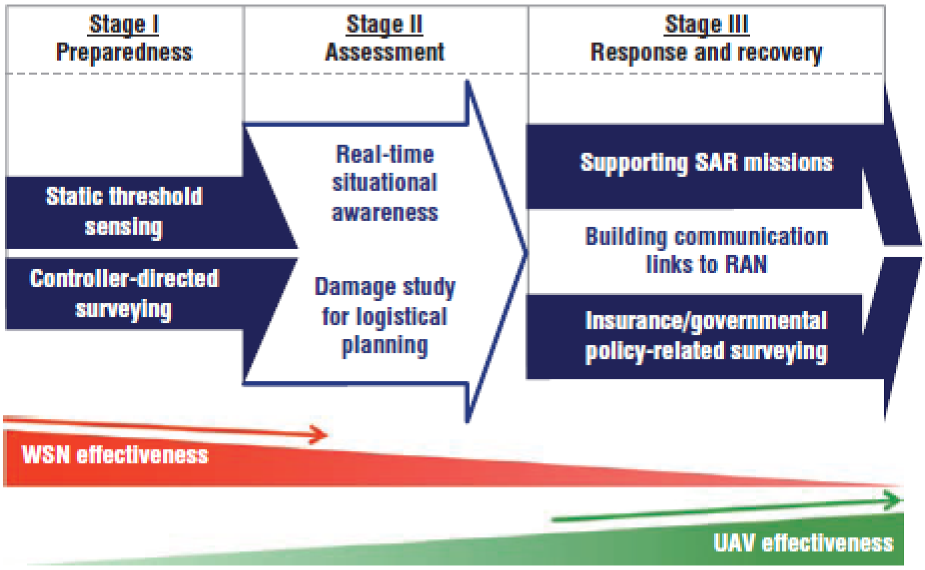


Figure 2.25: Use of UAVs in emergency management

2.13.4 Conclusions – Robotic Technologies in emergency management

Robotic is a mature technology and robots have been used in many emergency management situations. UAVs are increasing playing a greater role in emergency management. As discussed above both technologies requires further enhancements for wider use in emergency management.

2.14 Industry 4.0

2.14.1 Introduction to Industry 4.0

Driven by the need for a radical change in the manufacturing industry, the German Government through the Ministry of Education and Research and the Ministry for Economic Affairs and Energy, launched a national strategic initiative in 2011 to drive digital manufacturing forward (Skilton, & Hovsepian, 2017). This initiative brought together several digital technologies together and originated Industry 4.0 framework, which is considered the 4th Industrial Revolution.

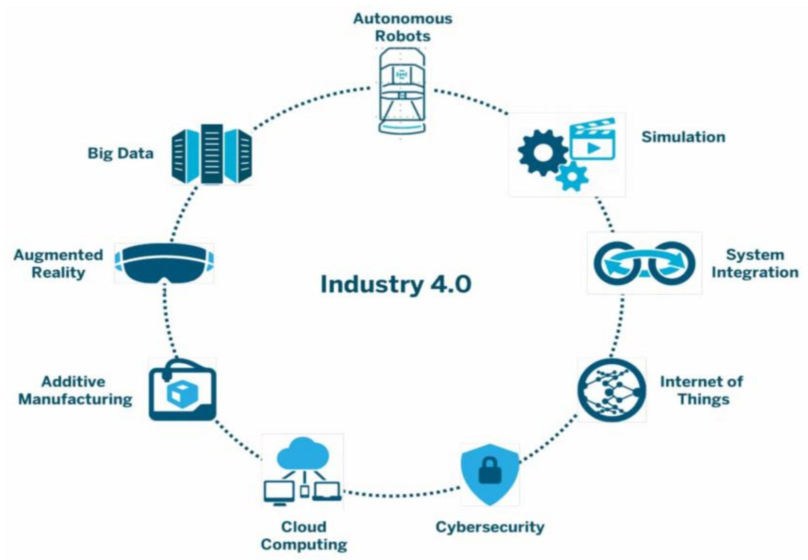


Figure 2.26: Industry 4.0 related technologies

As shown in Figure 2.26 Industry 4.0 is built on the assimilation of several digital technologies. Each of these technologies are briefly described below.

Additive Manufacturing – commonly known as 3D printing, is a computer-controlled process in which objects are created by depositing layers of material.

Augmented Reality – creates an experience of a real-world environment using computer-generated perceptual information.

Autonomous Robots – Robots with a high degree of autonomy which is built using artificial intelligence and sensor technologies.

Big Data – technologies for analysing very large volumes of data typically involve different data types (images, social-media and, voice etc. and real-time data, for example, sourcing from sensors.

Cloud Computing –refers to the delivery of computing services over the Internet.

Cyber-security – technologies developed to protect computer systems and networks from the theft of information and/or damage to hardware.

Internet of Things – internet connected devices which can transfer information between them without any human interaction.

Simulation – modelling technologies to develop computer models of proposed or real systems.

Systems Integration – technologies developed to integrate different systems to create whole systems.

By using a combination of the technologies above, it is also possible to create "digital twins" which is a"digital replica" of the real system [References]. Digital twins can be used to study the real system "off-line" and to generate optimum operating solutions for real systems.

2.14.2 Applications of Industry 4.0

Although it was primarily developed to move the digital agenda in manufacturing forward, many other sectors/initiatives are exploring the use of the Industry 4.0 framework. Examples from different areas are provided below.

Smart City Initiatives

The British Standards Institute (BSI) defines (Chatterjee & Kar ,2015) Smart City as

> *"the effective integration of physical, digital and human systems in the built environment to deliver sustainable, prosperous and inclusive future for its citizens"*

Given that smart city initiatives aim to integrate different technologies such as IoT, Cloud Computing and Big Data, Industry 4.0 framework fits well with smart city initiatives. Lom, Pribyl, & Svitek (2016) argue that Industry 4.0 can be seen as an integral part of smart city, in which linkages between process-oriented Industry 4.0 and intelligent transport system (which is considered a core pillar in smart cities) can create very effective and demand oriented systems. Karaköse & Yetiş, (2017) hypothesises that by integrating Industry 4.0 with smart cities, it is possible to achieve mass customisation of services. Postránecký & Svítek, (201) compare Industry 4.0 and Smart City concepts in terms of client, enterprise and facilitator dimensions and conclude Smart City is near to Industry 4.0. Safiullin, Krasnyuk, & Kapelyuk (2109) assert that Industry 4.0 provides a fundamentally new infrastructure and potentially solves the problems of resources utilisation and energy efficiency improvement.

Healthcare Sector

Industry 4.0 concept is also enabling the healthcare sector to achieve transformational changes. Giuseppe Aceto, Persico, & Pescapé, (2018) present an example how Industry 4.0 concepts could radically change Living Environments, Home-based Rehabilitation and Personalised Healthcare. Thuemmler & Bai, (2017) conclude that

> *"Industry 4.0 design principles work very well in the health domain, especially with regards to Precision Medicine and the rapidly progressive evolution of smart pharmaceuticals in chronic, non-communicable diseases"*

Wehde (2019) presents a case for the amalgamation of Industry 4.0 and modern healthcare technologies, which will reshape the healthcare industry. His analysis points to a shift away from the clinic-centred point-of-care model to a virtual and distributed care model using Industry 4.0 concepts. For example, 3D printing of tissue and implants and the use of robots will dramatically change the healthcare landscape.

Logistics and Supply Chain Sectors

Tjahjono, Esplugues, Ares & Pelaez (2017) propose a range of scenarios where Industry 4.0 be used for radical transformation of Industry 4.0 technologies. They argue that many processes can be totally automated by using cyber physical systems, robotics and artificial intelligence. In addition, they argue that supply chain visibility can also be immensely enhanced. Dmitry Ivanov and Alexandre Dolgu present a case for using digital twins, powered by Industry 4.0 technologies to manage disruption risks and resilience. Taking the impact of Covid-19 pandemic as an example, they argue that both predictive and reactive decisions can be generated and assessed by digital twins.

Other uses of "4.0" nomenclature

The literature review also identified that several smart technology-based initiatives which were tagged with "4.0" but used only a very limited range of technologies presented by Industry 4.0 framework. Thailand 4.0, Service 4.0 and Government 4.0 are some examples.

It is, therefore, important to note that not everything tagged with “4.0” relates to Industry 4.0 framework.

2.14.3 Digital Twins

The concept of digital twins became popular in the early 2000 when companies had started building “virtual replications “ of machinery and production systems (El Saddik, 2018). Prior to this, the nearest technology to digital twins was computer simulation, where models are built to mimic the operations of real systems. Simulation models, however, are “simplified versions” of real systems, as assumptions are made during the model building process. In contrast, digital twins are “exact” replicas of real systems. The advent of Industry 4.0 has accelerated the use of digital twins (Jiang, et al. 2021)

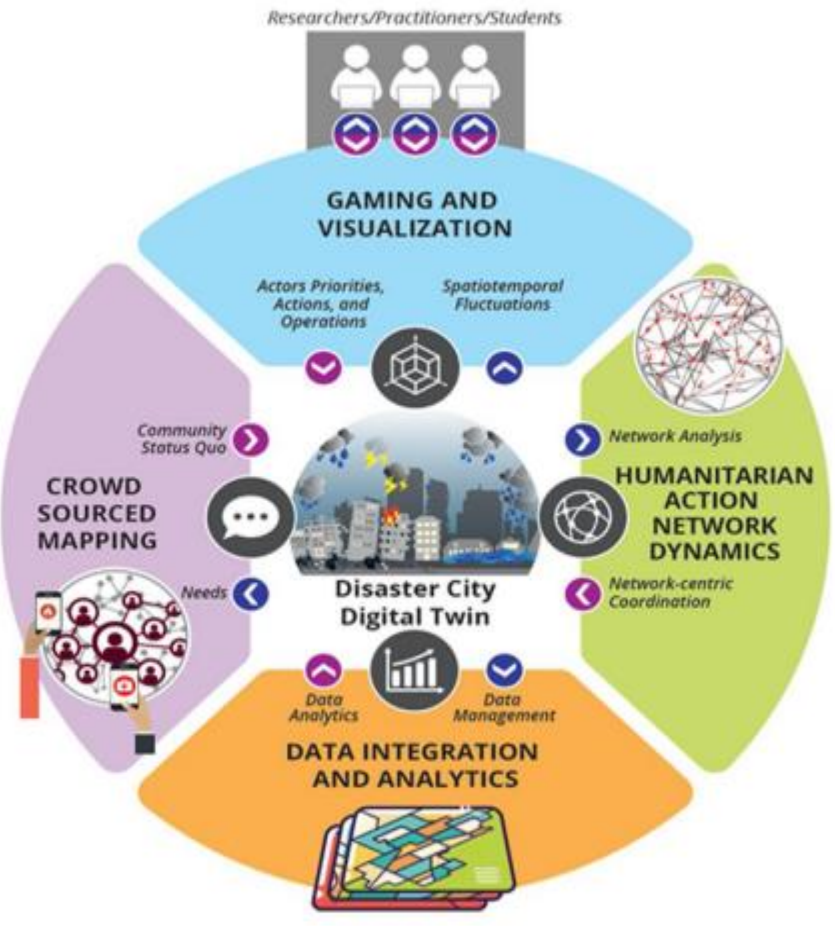


Figure 2.27: Components of a Digital Twin ((Jiang, et al. 2021)

2.14.5 Industry 4.0 in emergency management

As outlined in Section 2.10, over the years the emergency management community has been embracing new technologies to improve all phases emergency management cycle. However, the literature review did not find any evidence of a single framework which can "bind" those technologies in a systematic manner. Industry 4.0 framework potentially can fill this gap and further advance the use of technologies in emergency management.

The literature in this area is scarce as it is a relatively new topic in emergency management research. Schwertner, Zlateva & Velev (2018) propose the development of a highly integrated information management model using relevant technologies from the Industry 4.0 framework. But it should be noted that this proposal uses only a few Industry 4.0 technologies, namely Big Data and Systems Integration. World Economic Forum outlines the potential use of Industry 4.0 across the emergency management cycle. (Extance, 2015).

2.15 Conclusions

The literature survey provides an insight into how research work has progressed in three major areas relating to this research work; (a) emergency management cycles (b) technologies in emergency management, and (c) Industry 4.0.

In the area of emergency management cycles, the four-phase model is recognised as the de-facto standard. It has been used as the basis for research in related areas. With regard to technologies, there have been many research strands such as ICT and Automation. No research work has been reported on the development of integrated frameworks to bring these technologies together. Industry 4.0 provides a framework for systematic integration of the most promising technologies relevant to emergency management.

As Industry 4.0 technologies facilitates better integration and the secure and efficient use of data, two other technologies might become more viable within the context of emergency managements i.e., Knowledge Management and Digital Twins.

Following the literature review, three research questions, stated in the section 1.8, were revisited to assess their validity.

Research Question 1: What general enhancement are required to improve UAE National Response Framework?

Research publications on the UAE National Response Framework is very limited. It was not possible to identify the enhancements required to improve the NRF. Therefore, further work is required to answer this research question.

Research questions 2: What roles Industry 4.0 technologies might play in the enhancement of emergency management?

The literature review identified stand-alone applications of some Industry 4.0 technologies in emergency management, for example, autonomous robots. But no evidence was found on a holistic approach to the use of Industry 4.0 in emergency management. Therefore, this research question remains valid.

Research Question 3: What are the best ways to embed Industry 4.0 technologies in the UAE National Response Framework?

This extensive literature review did not find any evidence of previous attempts to embed Industry 4.0 in emergency management in a systematic manner. Therefore, these research questions remain valid and further work is required to identify the best ways to embed Industry 4.0 technologies in emergency management.

It can be concluded that the literature survey has identified a significant research gap i.e., lack of a framework to integrate Industry 4.0 technologies in emergency management. Therefore the primary of aim of this research is to design and develop a framework to integrate Industry 4.0 technologies in emergency management cycle.

Chapter 3: Research Methodology

3.1 Introduction

Research methodology is the backbone of any structured and systematic research programme. It is critically important that appropriate approaches, tools and techniques are identified, and their deployment is organised logically to produce the ultimate outcomes. This chapter, therefore, outlines the development of the research methodology and presents the research methods chosen for this study. A flowchart is presented to illustrate the steps involved in the research programme. A generic model developed by (Saunders, Lewis & Thornhill, 2016)., the Research Onion, is used to formulate the research methodology and select tools and techniques.

3.2 Research Methodology

Oxford Dictionary (Oxford dictionary, 2021) defines research as:

> *"The systematic investigation and study of materials and sources in order to establish facts and reach new conclusions"*.

Kothari & Carg (2014) define research methodology as:

> "*Research methodology is a way to systematically solve the research problem*."

The most important keyword in both definitions is *systematic investigation* i.e., there is a need to develop and articulate a logically connected programme of work, or a journey, that should be able to create, justify and validate research outcomes. This journey typically involves a wide range of tasks such as literature reviews, data collection, analysis, drawing conclusions and creating new propositions and finally producing new knowledge. Sutrisna (2012) argues that a sound methodology is important in connecting these elements into a coherent whole.

Pathirage, Amaratunga and Haigh (2005) advises that it is vital to consider the research methodology, and it is important to consider philosophical and methodological issues that lie in the background of any research. Travers (2001) laments that the literature on research methodology fails to explain the difference between research methods and the methodology. Tuchman (1994) asserts that research methodology should extend beyond data collection methods and include epistemological (the nature of knowledge) and ontological (the nature of reality) assumptions. Nested models proposed by Kaglioglou et al.(1998) and Saunders, Lewis & Thornhill (2012) ,Saunders et al. (2012) aim to bring epistemological and ontological assumptions as well as research methods into a single model.

Kagioglou et al., 1998 proposed the nested model shown in the Figure 3.1 which include three layers.

Figure 3.1: Three layer nested model (Kagioglou et al., 1998)

Starting from the outer layer, the model steps through three layers to create the research methodology. The most recent research work, Melnikovas, (2018) and Abdelhakim, (2021), however, have used a comprehensive 6-layer Research onion (Figure 3.2) proposed by Saunders, Lewis & Thornhill (2012)

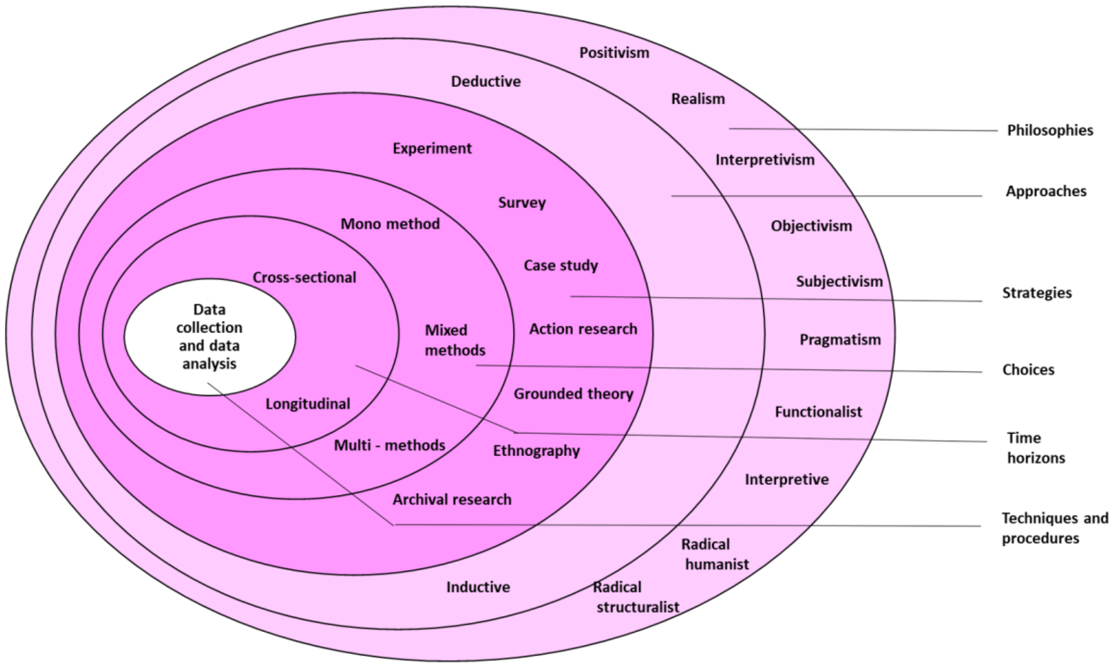


Figure 3.2: Six later Research Onion (Saunders, Lewis & Thornhill, 2012)

Given that the Research Onion model depicts each layer in detail, it is used to describe the research methodology adopted for this work. Becker et al. (2012) argue that its usefulness lies in its adaptability for any type of research work, and it can be used in a variety of situations. Each layer of the onion describes more details and options available in each layer. It enables researchers to develop research methodology in a systematic manner. The following sections explain each layer in detail and which options have been used for this research programme.

3.3 Layer 1 – Philosophies

Research philosophy is an important part of any research methodology. It is the viewpoint on which research work is based and the set of assumptions, concepts, practices and values which explain the research area (Johnson & Christensen, 2019). Layer 1, philosophies, include 10 different approaches which are based on different ontological, epistemological, and axiological (study of values) assumptions.

Ontological assumptions focus on the nature of reality with two opposite ends, 'objectivism' and 'subjectivism'. Objectivism assumes that there is an external reality that is not influenced by individuals. In contrast, the subjectivism assumes that there is no such independent reality and the viewpoints are influenced by individuals. During the initial investigations, it was noted that different stakeholders commented on the limitations of the UAE Emergency Management Framework in different ways. Therefore, a **subjectivist approach** focusing on the views of the key stakeholders was selected for this research work. This enabled the researcher to understand the viewpoints and opinions of stakeholders involved in the design and implementation of the UAE Emergency Management Framework.

Epistemological assumptions focus on the nature of knowledge. It relates to the knowledge creations process. Like Ontology, Epistemology also has two opposing positions, positivism and interpretivism. Positivism approach aims to endorse known knowledge through a research process, for example, the law of gravity. Interpretivism on the other hand, suggests that knowledge creation is affected by stakeholders. Thus, the research aims to develop a new framework (i.e. new knowledge), **Interpretivism** is the most suitable approach.

Axiological assumptions help to decide what should be considered as valued information for research. It also helps to decide how the value of data should be interpreted. Sekaran (2006) states that axiology affects the choice of data used and how data and its collection techniques are valued. Saunders, Lewis & Thornhill (2012) present the following options for axiological assumptions in relation to data collection.

Axiology	**Description**	**Data Collection Methods**
Positivism	Research is undertaken in a value-free way, the researcher is independent from the data and maintains an objective stance.	Highly structured, large samples, measurement, quantitative can also use qualitative.
Realism	Research is value laden; the researcher is biased by world views, cultural	Methods chosen must fit the subject matter, quantitative or qualitative.

	experiences and upbringings. These effect research findings.	
Interpretivism	Research is value bound, the researcher is part of what is being researched, cannot be separated and so will be subjective.	Small samples, in-depth investigations, qualitative.
Pragmatism	Values play a large role in interpreting results, the researcher adopting both objective and subjective points of view.	Mixed or multiple method designs, quantitative and qualitative.

Table 3.1: Axiology and data collection methods (Saunders, Lewis & Thornhill, 2012)

Given that this research involves both objective and subjective points of views, pragmatism is considered as the most suitable axiological philosophy for this research programme.

3.4 Layer 2 – Approaches

This layer presents two contrasting approaches to research, deductive and inductive, also known as top-down and bottom-up approaches, respectively. Deductive research begins with a theory and applies it to data. Inductive research typically starts with collated data which is used to generate a theory Collis & Hussey (2013), William Trochim (2006)**.** The main differences are summarised in table 4.2.

Deductive approach	Inductive approach
Scientific principles	Gaining an understanding of the meanings that humans attach to events
Moving from theory to data	A close understanding of the research context
The need to explain casual relationships between variable	The collection of qualitative data
The application of control to ensure validity of data	A more flexible structure to permit changes of research emphasis as the research progresses
The operationalisation of concepts to ensure clairty of definition	A realisation that the researcher is part of the research process
A highly structured approach	Less concern with the need to generalise
Researcher independence of what is being researched	
The necessity to select samples of sufficient size in order to generalise conclusions	

Table 3.2: Deductive and inductive approaches (Saunders et al., 2009)

This research will use both deductive and inductive choices. In early stages of the research deductive approach is used to identify issues, models and challenges in emergency management. In the later stages of the research, the inductive choice is used to create a framework and recommendations.

3.5 Layer 3 – Strategies

Researchers have various research strategies at their disposal. They include surveys, case studies and archival research etc. Yin (2003) suggests that there are three factors that researchers can use to decide on required strategies.

a) the nature of the research question

b) the amount of control that a researcher can be expected to have over the behaviour that they are investigating

c) whether the research is investigating contemporary or historical events

Strategy	From of research question	Requires control over behavioral events	Focuses on contemporary events
Experiment	How , why	Yes	Yes
Survey	Who, what, where, how many, how much	No	Yes
Archival analysis	Who, what, where, how many, how much	No	Yes/No
History	How , why	No	No
Case study	How , why	No	Yes

Table 3.3: Research Strategies (Yin ,2003)

To fulfil the requirements of the research objectives, surveys and case studies are to be used in this research.

3.5.1 Surveys

Surveys are deployed to collate primary data. Surveys can be broadly divided into two categories, interviews and questionnaires.

Interviews - Interviews are considered as a personal form of research, where primary data is collected through face-to-face or telephone meetings (Jamshed, 2014). Interviews provide opportunities to probe or ask follow-up questions to uncover details relating to the topics. Interviews may also provide opportunities to discover areas for further investigations.

Questionnaire Surveys – These are logically designed to collate the required primary data in a much more systematic manner (Arsham, 2005). They typically consist of questions with a range of possible answers and/or statements that are rated according to a specific scale.

3.5.2 Case studies

Yin (2018) states that "case study analysis is an in-depth inquiry into a topic within its real-life setting." In general terms, the "case" in a case study refers to different things such as organisation, person or a specific topic. In this research work, "cases" are "the deployment of Industry 4.0 technologies" in emergency management. The case studies are required to formulate a technology map which is an integral element of the framework.

3.6 Layer 4 – Choices

This layer presents three (3) choices, mono methods, mixed methods, and multi-methods

- Mono method study uses only one method, one quantitative or one qualitative.
- Mixed Method study uses both qualitative and quantitative methods.
- Multimethod research entails the application of two or more sources of data or research methods

This research will use both qualitative and quantitative data; hence the chosen choice is Mixed Method.

3.7 Layer 5 – Time horizons

This fifth layer refers to the time framework for conducting research. As shown in (Figure 3.2), there are two options under time horizon, cross sectional and longitudinal. Flick (2015) states that cross-sectional studies are set to have a specific time period for data collection.

Goddard and Melville (2004) state that longitudinal studies collect data repeatedly to meet the requirements of the research programme.

In this research work, data has been collected at several points. Primary data was collected from surveys and case studies and secondary data from the literature review. Therefore, this research has been carried out in a *longitudinal time horizon* involving a process which took place over a period of time with both primary and secondary data collections.

3.8 Layer 6 6 – Techniques and Procedures

The core of the Research Onion model refers to data collection and data analysis. In this work, surveys and case studies are used to collect primary data and literature surveys to collect secondary data which have been explained in detail above.

3.9 Summary - Selected Options from the Research Onion

The table below summarises the options selected for this research programme.

Layer	Chosen Options
Layer 1 – Philosophies	Ontological assumptions - Subjectivist Epistemological assumptions – Interpretivism Axiological assumptions – Pragmatism
Layer 2 – Approaches	Both deductive and inductive
Layer 3 – Strategies	Surveys, Case studies
Layer 4 - Choices	Mixed Method
Layer 5- Time Horizons	Longitudinal
Layer 6 Techniques and Procedures	Questionnaires, Surveys, Case studies

Table 3.4 : Selected options from the Research Onion (Author)

3.10 Research Design and Process

(Figure 3.3) depicts how tools and techniques identified above have been implemented in this programme of research.

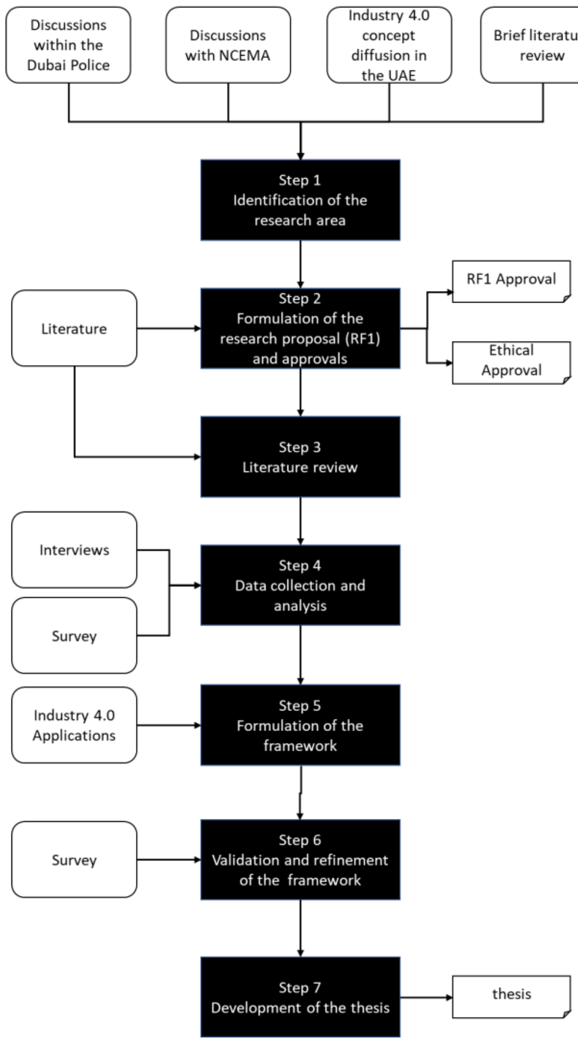


Figure 3.3 – Research Steps (Author)

Step 1: Identification of the research area

As an employee of the Dubai Police, the researcher has a good awareness of emergency management. As the concept of Industry 4.0 concept gradually became known in the UAE, discussions started within the Dubai Police on the potential use of Industry 4.0 technologies. NCEMA (The National Emergency Crisis and Disasters Management Authority) is the governmental organisation responsible for the emergency management of the UAE, discussions were extended to a few senior managers to explore the potential development of a research theme in this area. These discussions concluded that it is worth exploring the possible use of Industry 4.0 technologies in emergency management. A brief literature review also indicated that there is an opportunity to develop a programme of research in this area.

Step 2: Formulation of the research proposal and approvals

Further review of the literature revealed that the emergency management researchers have been exploring the use of Industry 4.0 technologies in isolation, but there was no evidence of any research focused on the development of a systematic approach to integrating Industry 4.0 technologies in emergency management. Hence the main aim of this research programme was set as the design and development of a framework for embedding Industry 4.0 technologies in the UAE emergency management framework. In addition to the development of the research proposal, further documents were prepared to obtain the required ethical approval. Interviews and surveys require prior ethical approval.

Step 3: Literature Review

An extensive literature review is an essential element of programme of research leading to a PhD. It covered a wide range of topics ranging from known emergency management models to use of Industry 4.0 technologies in various of phases of emergency management cycles. One of the challenges of the literature review was the lack of publications on the of the emergency management framework. This extensive literature review endorsed the initial finding that to date no research has taken place to integrate Industry 4.0 technologies in emergency management cycles.

Step 4: Data collection and analysis

Given the lack of literature on emergency management in the UAE, it was decided to conduct a series of interviews with senior stakeholders of NCEMA and a questionnaire survey with NCEMA and other stakeholders such as the Dubai Police.

Step 5: Formulation of the framework

This is the centrepiece of the research programme. Information gathered from previous stages were systematically synthesised to create the backbone of the framework. Key building blocks and their roles were identified and described in detail. Following the establishment of the draft framework, a validation exercise was carried out to assess the usability and coherence of the proposed framework. Some adjustments were carried out to produce the final framework.

Step 6: Production of the thesis

As the final stage of the research programme, this thesis was produced to document the entire programme of research and contributions to the new knowledge.

3.11 Summary

The main purpose of this chapter is to outline the selection of research philosophies and approaches for this programme of research. Using Saunder's Research Onion Model, appropriate choices were selected for each layer. Table 3.4 summarises the choices, and the (figure 3.3) shows how chosen tools and techniques have been implemented in this research work. Further details of tools and techniques are provided in the following chapters.

Chapter 4: Primary Data Collection and Analysis - Interviews and Questionnaire Survey

4.1 Introduction

One of the challenges of this research programme was a lack of academic studies on the UAE Emergency Management framework, which means that the secondary data on this topic is limited. Consequently, the collection of primary data through interviews and questionnaire surveys is far more important in this research work. This chapter reports on the design of primary data collection approaches, data collection process and analysis.

4.2 Primary Data Collection

Within the context of this programme of research, primary data refers to data collected directly from main sources through interviews and a questionnaire survey. As reported in Chapter 2, academic literature on the UAE Emergency Management framework is limited. Therefore, it is critically important that the researcher develop a good insight into the current status of the UAE Emergency Management Framework and potential opportunities for improvements particularly through the integration of technologies. This data collection was carried out in two stages, interviews and a questionnaire survey.

For interviews, a group of key stakeholders who contribute to the development and deployment of the UAE Emergency Management Framework were identified. One-to-one interviews provided opportunities to gather the required data and any other ancillary data through follow up questions. The Questionnaire Survey targeted a wider audience, primarily those responsible for executing the framework.

4.3 Interviews

Interviews are a qualitative research technique that involves “conducting intensive individual interviews with a small number of respondents to explore their perspectives on a particular idea, program or situation.” (Boyce & Neale, 2006). Interviews are used to gather information from individuals about their own practices, views and opinions. Interviews are also used to tap into the expert knowledge of an individual.

Interviews can be conducted with individuals or with a group, commonly known as focus groups. Knodel (1993) and Morgan (1998) argue that individual interviews produce more detail information than focus groups and provide more insight into a respondent's personal thoughts and views. Therefore, in this research, it was decided to conduct individual interviews.

Interviews have been classified according to the level of control exercised in the interview process; unstructured, semi-structured and structure with unstructured being the least level of control exercises.

Unstructured interviews - the researcher must have a clear plan but minimum control over how the interviewee answers. Discussion can go in many directions; hence unstructured interviews may potentially produce a rich set of qualitative data. However, analysis can be challenging and time-consuming.

Structured interviews – are the most controlled type of interview, which typically consist of a fixed set of questions on a specific order; it is very similar to the questionnaire survey. However, Fowler (2002) argues that structured interviews have several advantages over surveys. The benefits include lower levels of nonresponse and the ability to mitigate inappropriate responses.

Semi-structured interviews – Similar to structured interviews, the process is guided by a set of pre-prepared question, with the researcher having the freedom to explore specific areas deeply to gather further information. This ability to probe specific areas helps the researcher to develop a better understanding of the subject area.

Given the limited literature available on the topic of the UAE Emergency Management framework and its uses of technologies, it was decided to use a semi-structured interview approach as it enables the capture of interviewee views on all necessary topics and gathers further details where necessary.

4.4 Interview Process

Silvia E. Rabionet (Rabionet, 2011). outlines the key stages involved in conducting qualitative interviews:

Stage 1: Selecting the type of interview

Stage 2: Establishing ethical guidelines

Stage 3: Crafting the interview protocol

Stage 4: Conducting and recording interviews

Stage 5: Analysng and summarizing interviews

Stage 6: Reporting the findings

How the above stages were implemented in this research are explained below:

Stage 1: Selecting the type of interview

As explained above, the *semi-structured interview process* was adopted for this research as it gives freedom to explore details where it is necessary.

Stage 2: Establishing ethical guidelines

As required by the host institute, Sheffield Hallam University, ethical approval for the proposed work was obtained for this work at the outset. As an employee of Dubai Police, the researcher was required to apply for further ethical approval as stipulated by the rules and regulations of the institute. Dubai Police also granted ethical approval for this work.

Stage 3: Crafting the interview protocol

This stage involves three key steps:

Step 1: Developing key questions

The primary aims of the interviews were to (a) identify strengths and areas of improvement of the UAE Emergency Management Framework and (b) identify the role of technologies. Therefore, the interviews focused on four (4) major areas.

Question	Purpose	Potential supplementary questions
What are the key strengths of UAE National Framework?	To understand key strengths of the framework.	Has there been any benchmarking of these strengths?
Are there any areas for potential improvement?	To capture major weakness of the framework, if there are any.	What actions have been taken so far to address these weaknesses?
What specific technologies are used to support the implementation of the framework?	To understand which technologies have been identified to support the implementation of the framework.	How/why these technologies have been identified? Are there any examples of using these technologies?
What other technologies might be useful?	To identify the potential use of emerging technologies.	What interviewees know about Industry 4.0?

Table 4.1: Interview Questions (Author)

Step 2: Developing interview checklist
The following general information was recorded for each interview:

Participant Name:	Organisation:	Role in the Organisation:
Place of the Interview:	Date of the Interview:	Duration of the Interview:
Language interview conducted:	Electronic Copy: YES / NO	

Table 4.2: Interview Checklist (Author)

Interview checklist included

- *Start with Introductions*
- *Share the purpose of the interview*
- *Seek permission to record the interview*
- *Conduct interview (focusing on key questions and supplementary questions where necessary)*
- *Seek additional comments from the interviewee*
- *Share a summary of key points and close the interview*

Stage 4: Conducting and recording interviews

Step 1: Pilot Testing

Kvale, 2007 states that pilot testing enables the researcher to identify any flaws and/or limitations of the protocol. Therefore, two pilot interviews were conducted with two senior executives from Dubai Police. Their feedback included:

- The researcher conducted the interview in a professional manner.

- More supplementary questions may be required as some interviewees may be reluctant to share areas of improvement. It was suggested to capture the interviewee’s views on any known weaknesses.

- Interviewees may not be aware of Industry 4.0; therefore, a simple introduction to underlying technologies should be included.

Step 2: Sharing a pre-interview guide

At the request of the interviewee, the following headline questions were sent in advance of the interview. The interviewee indicated that other members of the team may be approached to gather further information to provide comprehensive answers.

- What are the key strengths of the UAE National Framework?
- Are there any areas for potential improvements?
- What are specific technologies used to support the implementation of the framework?
- What might other technologies be useful?

Step 3: Conducting Interviews

Five (5) senior executives and managers from NCEMA were chosen as interviewees. They were selected from different areas of NCEMA so that a broader picture could be generated.

Stage 5: Analysing and summarizing interviews

In the following, a summary of each interview is presented. To minimise duplication, some facts are recorded only once. Personal introductions and the explanation of the research program have been excluded from the summaries below.

Interview A

Interviewee - A senior executive of the Dubai Emergency, Crisis and Disaster Center

Interviewer: Good afternoon, It would be good, if we could start the meeting with a brief introduction to your role.

I have been working at NCEMA as a senior executive (job title was removed) for more than 14 years. I started at a middle management post in the area of information technology then progressed to take up the current executive post. Since I joined NCEMA, I developed a deep understanding of emergency management in the UAE. I am currently responsible for the overall delivery and management of NCEMA.

It is good that you are working on a research programme in this subject area. We need this kind of research to understand future directions for the development of our framework. You are the first person that I met doing PhD research in this area. I welcome *a meeting after you have completed you research programme to see how we can use your work to identify further improvements to the framework.*

Interviewer – "Yes I would very much like to meet you after I have completed my research work".

As you are aware, our national framework was established in 2013. Until NCEMA was established in 2007, there was no national framework. Each government department/organisation was responsible for developing their own ways to deal with emergencies. The government eventually recognised the need to set up a single body. That is how NCEMA came to operations. Do you have any questions about the history of NCEMA?

Interviewer: Yes, a bit more detail would be useful.

Following a decree from the President of the UAE, NCEMA was setup under the supervision of the Supreme Council for National Security in 2007. NCEMA is responsible for developing policies, standards, regulations, and legislation for emergency management. It is also responsible for drawing up strategic plans and coordination to unify the response at the local level and external cooperation. Until this happened, there was no concept of a national framework. Every governmental institution used their own procedures in emergencies. So, police, ambulance and rescue services were working on their ways to handle emergencies with little or no coordination between them. There was no coordination at federal level at all. As the economy was growing fast and the overall population was increasing due to an influx of migrant workers, the federal government saw the need for a much more coordinated approach, hence the birth of NCEMA. It not only helped to improve emergency management approaches in the UAE but also to consolidate international cooperation and efforts. I hope this information is useful. Any other questions on the setting up NCEMA?

Interviewer – "Thanks for that information. No, I don't have any questions on the setting up of NCEMA. So shall we focus on the first question? "

Yes, of course, I am going to go there now. Before that, I wanted to make sure that you do not have any questions on NCEMA. As I told you before, I spoke to some of my *colleagues about your interview questions before this meeting. I wanted to make sure that I give you the best possible answers. So, on the question of strengths, there are many answers.*

One of the strengths is the existence and laws and regulations set by the UAE government. These laws and regulations are applied to all seven emirates. So, we have a very consistent approach, all local bodies follow the same laws and regulations. This makes our life easy.

Interviewer:" If a local body identified a specific requirement, how you deal with that?"

That is a good question; we have a system in place to gather requests from local bodies. We then discuss these requests in our senior executive team meetings and see whether any changes are required to the national framework.

NCEMA works with the central government to ensure laws and regulations are regularly updated to ensure all emirates are aware of changes. This makes our life easy. We do not need to deal with different sets of laws and regulations. I think this is a major strength of our system. We take local considerations into account but always a single framework to govern all emirates. I hope this is clear?

Interviewer - "Yes it is very useful. Can you tell me a little bit more about local bodies?"

Ok, so in each emirate, under the resolution of the crown prince, there is a local team headed by the local police chief. These interact with NCEMA on a regular basis. They are also responsible for setting up local operational plans to deal with emergencies but remain under a single set of laws and regulations. They are also responsible for the creation and maintenance of local risk register. This takes me to the next strength that I want to share with you, the risk register.

So, we now have well-established procedures to maintain a national and local risk register. Many years ago, this was very disjointed. Local bodies are responsible for developing local risk register, and at the national level NCEMA maintain the national risk register. It was a great a step forward. Before NCEMA was established, every government institution had its own risk register. Thus, there was no single risk register. In 2012, NCEMA established a training programme, "Preparing the risk register for institutions and *federal and local departments", in cooperation with the College of Emergency Planning in Britain. Only after this, did we managed to produce local and national risk registers. We also use Disaster Recovery Institute International (DRI) regularly to train our staff and update their knowledge.*

The National Operations Centre has been established in Abu Dhabi at the headquarters of the Authority. It works on advanced technologies and technology, in addition to establishing subsidiary operations centres in each emirate. The authority has many cooperation and agreements. An emergency management training centre has been established, for example, the British Government Centre in GCC Countries, Pakistan and Jordan, the Gulf Cooperation Council Disaster Recovery Foundation, Jordan, Egypt, and City and Guilds.

So, in terms of strengths we are also very proud to have a well-integrated response system. We have worked very hard to develop this system in collaboration with local teams. We have put this into practice on several occasions.

Interviewer – Sorry to interrupt, can you give me any examples of where the response system has been used in recent years?

We use our system in the UAE and when our support is requested by other countries. Let's talk about a few examples in the UAE. Tropical cyclones happened several times in 2007 and 2010. A mass fire in a on New Year's Eve 2016 is another example. Also in 2016, an Emirates aircraft accident at Dubai Airport was a major incident. We also assist neighbouring countries, if we are asked to help. For example, we put our systems into practice when Jordan and Egypt asked for our help.

So just to complete the answer to your first question, I must say that NCEMA is proud of its achievements; we worked very hard to develop a unified system. As you know, UAE is constantly leading the world by organising large-scale events such as Expo 2020, so we need a very robust and modern emergency management system. I think we have achieved that. It is a great success for the whole of UAE.

Interviewer – Thanks for those insights, very useful. Before, we talk about potential areas for improvements, can you give some examples of how technologies have been used to develop your systems?

That is a good question. I want to start with the development of the Early Warning System, which we call it EWS. I think it is pretty unique in the region. We took the guidance provided by the United Nations. They say EWS should be able to send clear, understandable, and timely warning information to communities and organisations. We worked with the Telecommunication Regulatory Authority and major mobile service providers in the UAE, Etisalat and Du, to develop a system to send early warnings to all mobile users. What is really important here is that the Telecommunications Regulatory Authority (TRA), issued a law enforcing new phones entering the UAE market should be compatible with the requirements of the early warning system. Our approach is to ensure that everyone is kept informed of early warnings.

The other technology that we have been using for a long time is GIS. As you know, GIS is a very popular technology used in emergency management. We have set up a special department to deal with GIS development. Until 2010, there was no coordinated approach to using GIS in the UAE. We saw this gap and proposed the concept of a National Spatial Data Infrastructure (NSDI). This was a big step forward. We engaged a very reputable GIS company in the USA, GeoDecsions, to help us. So now, GIS is an essential part of our armoury when dealing with emergency situations.

We are now also using business intelligence tools to modernise our information management systems and to create more visuals to support decision making. I don't think we need to discuss this in detail as it is a popular tool in many industries.

Interviewer – It is good to hear that you are exploring many new technologies. Can you tell me any other technologies which are currently being considered?

You may guess this. We are very serious about AI. We think it can help us to improve our systems further. We discussed this with international experts at our most recent conference, the 6th Crisis and Emergency Management Conference (CEMC 2019) organised by us. At this conference, I mentioned that we should learn from experiences in

Singapore and Italy on how they use AI. It is early days for us, I am sure we will explore the use of AI very seriously in coming years. I know there are a lot of new technologies coming. We need to explore them.

Interviewer – Yes, I agree AI is the future. Have you heard of Industry 4.0?

Yes, I have heard about it, but I don't know much about it.

Interviewer – Finally, I want to ask you about any areas of improvement.

Yes, we are working on several areas. The first thing is that we can create a central database to record all incidents. At the moment, we are working with different systems. If we can bring all relevant information into one place, we can do better analysis and make better decisions. So we are now working on this.

We also need to improve the local scientific knowledge base. We would like to see local universities taking initiatives in this area. I think this will slowly happen.

We also need to make an e toffortmake people aware of this. I don't think the society is generally aware of the importance of emergency management system. We have a very large pool of foreign workers in the UAE, so it is very challenging for us. I think, the overall risks are increasing in the region, so we have a duty to make sure that everyone has some understanding of emergency management efforts. We should not wait until something goes wrong to learn new things!

Interview B

Interviewee – Senior executive of Department of Communications and Technology

Interviewer - Good afternoon. Can you tell me about your role and responsibilities within NCEMA?

One of the primary responsibilities on which my job is based is to develop technologies for telecommunications networks and data centres to ensure the continuity of their work and the necessary support for emergency management decisions using technology such as geographic information systems.

Interviewer - Thanks for that. If it is OK with you, I would like to start with the first area for discussion which is the key strengths of the UAE National Framework.

I think our greatest achievement is the establishment of the national framework. We worked hard over many years to establish our framework. Before there was no national effort, all actions were very disjointed, so the UAE government setup NCEMA in 2007 as a central body to develop a national framework and lead and coordinate its implementation.

That is a bit of background. You asked me about the strengths of our framework. I think probably the most important strength is the coordination with local bodies (in each Emirate) and national bodies. We have tested this at several incidents. It worked well. Of course, we had few teething problems.

Interviewer – Sorry to interrupt, what were the main challenges?

Sometimes, communications with local bodies did not work very well. We also noticed that some parts of the framework were not clear. So we learned from these experiences and continually improved the framework. As a part of this continuous improvement programme, we started developing "The National Early Warning System". In fact, this project is considered one of the most important projects of the authority. EWS aims to warn citizens at the shortest possible time when there is a major incident. We achieved this through activating the communication system via cell phones, in coordination with the Communications Regulatory Authority and telecommunications companies. Actually, we used the guidance provided by the United Nations on the development of early warning systems. This development is going well, and you will hear more about this in future, I think this is a very important development. We should be able to reduce the impact of disasters with this system. I hope this information is helpful.

Interviewer – Have you encountered any problems with this development?

Yes, we faced some difficulties which are still present, as the warning text messages may not suit the types of phones currently in place, and visitors to the country may not benefit from this system, but we are still working to correct these errors.

Interviewer - Does the public trust the messages from the early warning system?

Only certain institutions can send messages. They are the National Emergency Crisis and Disaster Management Authority, the police leadership in every emirate in addition to the Ministry of Health. So there is no issue in that sense.

Interviewer – Yes, of course. Shall we focus on areas for potential improvement?

As I said a minute ago, we are continually improving the framework from the lessons that we learn from the use of the framework. We also look at the framework from other countries and we are attempting to understand their best practices. It is a continuous process. We also continually look for new technologies that can help us. I think this is going to be a big area in future. I am glad that you are looking into this area. As you know, technologies can play a major role in disaster recovery stages and before, for example, the early warning system that I mentioned. I am sure you have heard about the use of drones in emergency situations. We very much look to use these emerging technologies, but of course we need a clear strategy to identify, introduce and implement new technologies. That is the key to the successful implementation of new technology. If not done systematically, it can cause more problems rather than solving problems. I am sure there are many other technologies that we can use.

Interviewer- You said that it is important to have a strategy to identify, introduce and implement new technologies. Do you have a team or a department responsible for this?

The truth is that there is no specific work team in monitoring and introducing modern technologies in particular, but the Technology and Communications Department is responsible for providing and developing communication network technologies and *modern technology and providing the National Operations Centre and the branches of the local centres with these modern technologies.*

Interviewer – Thanks for that information; very helpful. Shall we discuss current technologies being used?

In Dubai, we use technology to monitor "fog density". This system uses a highly advanced "Visibility Modelling and Forecasting System" developed in Slovakia. This system sends live data to operation centres such as Dubai Police. They then put warnings to drivers through radio messages and digital signboards. You may remember the Ghantoot accident in 2008 with a nearly 200 car pile-up. We aim to avoid these types of incidents in future.

We also set up a seismological network to monitor earthquakes back in 2006. Since then, the systems have been improved several times; for example, it is now connected to neighbouring systems in the Gulf region. In recent years, Dubai Municipality also set up Smart Structural Health Monitoring Systems on the key buildings such as Burj Khalifa, the world's tallest building. We also use SARMaster system to manage search and rescue missions.

Interview C

Interviewee – Senior Executive of the General Directorate of Operations and Coordination in Crises and Disasters

Interviewer – Good morning, thanks for giving me this opportunity. Before we start on discussing emergency management, please tell me a bit about your background.

One of the most important responsibilities that fall on my shoulders is logistical support and support for continually improving the efficiency of emergency management and its capabilities. I am also responsible for the preparation and development of specialised training, with the aim of raising the level of employees' awareness of the policies and systems of response frameworks at all stages of emergency management. I am also *responsible for preparing the budget and managing financial accounts, contracts and purchases.*

Interviewer – Thanks for that introduction. So, I would like to start asking you about the national framework and its strengths.

As you may be aware, our framework is relatively new compared with many other countries. Only after NCEMA was established in 2007, the country manage to develop a framework before that had very disjointed approaches. The framework has brought all parties under one umbrella. I think that is the main strength of the framework.

Interviewer – Thanks for that input, very useful. Now, I would like to know your views on any improvements required for the framework to make it more robust and effective.

We are continually making improvements, but I think we need to do further work to improve it We need to continually learn from other countries where national frameworks have been operating for many years, for example, Japan, USA and UK. Our colleagues always attend major international events such as conferences to learn more about new developments. One area that we need to improve is a further development of guidelines for emergency simulations and drills. We do this now, but we need to do more of these as we never know what kind of new situations may emerge in the future. Again, we can learn from experiences in other countries to develop a much more systematic approach to emergency simulation and drills. In my role as the lead for operations and logistics, I also would like to see some improvements in procedures. We need to continually improve them to save lives and reduce their impact on society. We organised the Emergency and Crisis Management Conference in Abu Dhabi in 2016. It was a very successful event and helped us to develop more cooperation with other parties. One other thing that I would like to mention is that we are not good at measuring the impact of the changes. I think this is vital, and it should be an essential part of continuous improvements.

Interviewer – Yes, few other participants also mentioned the need for continuous improvements. Can we talk about the use of technologies in emergency management?

Yes, of course. One of the areas that we worked on recently was the use of technology to educate the society on emergency management. We teamed up with the Telecommunications Regulatory Authority so that key messages are broadcast to people using the government website and social media platforms. We are also in the process of setting up a system to share/exchange practices and new ideas with other nations. As you may be aware, we have heavily invested in GIS-related technologies.

Interviewer – Thanks for those valuable points. I would like to explore one more area with you, that is any new technologies that might help NCEMA to improve planning and emergency responses.

I think we need to explore the use of modern technologies such as augmented reality to improve our training programmes; this technology will certainly help us to do better emergency simulations. This is one of the areas that we need to strengthen. We need to train our people to deal with any complex scenarios. So augmented reality is something that I would like to consider seriously in my area of work.

Interview D

Interviewee – Senior executive of the National Operations Centre for Response

Interviewer – Good morning, it would be good if we could start with the responsibilities of your role.

My main responsibility is to ensure that all required departments work together in the event of a disaster. I use the guidance provided in the UAE emergency management framework in most instances. Another important role is sharing the information gathered during emergencies with other departments and stakeholders.

Interviewer – What can you say about the strengths of the national framework?

I think, overall, it is a good framework. NCEMA is continually improving the framework. The framework requires us to work with various other departments to update the national and local risk registers regularly. This is very important to us as we need to prepare for any new risks/threats. Once we have identified a new type of risk/threat, we plan and conduct exercises with other departments.

Interviewer - Thanks for that, it would be good to know about the use of technologies.

To me, the most important technology is communication technology. In my role (response), the use of communication technologies is critical to ensure that my authority (departments) can respond to emergencies efficiently and effectively. This is critical not only for coordination between departments but also to inform the public swiftly. At the end, the most important thing is to minimise the impact on the public. So, to me, communication technologies are critically important.

Interviewer - any other technologies?

The other important technology that we use is robotics. We are one of the first nations in the world to use unmanned aerial vehicles (UAV) in search and rescue operations. Actually, our team also used UAVs during the relief efforts after the earthquake in Nepal, 2015. We can see the important roles that UAVs can play in emergency management. Our government was so keen on the UAV technologies that they launched an international competition, "Drones For Good" in 2014. Our government now sponsors bi-annual international competition, the Mohamed Bin Zayed International Robotics Challenge. These kind of competitions help us to identify new systems that we can potentially use. There is no doubt that robotics will play a major role in emergency management.

Interviewer – This is very interesting. I am wondering whether there are any opportunities for improvement?

Yes, of course, I think we need a better approach to identifying the potential use of new technologies. At the moment, we don't have a clear strategy to identify new technologies. In the beginning you mentioned Industry 4.0. We have heard about it, but we don't know much about it. So, I think we certainly need a logical approach to identify the potential use of new technologies in emergency management.

Interview E

Interviewee – Senior Manager of Information & Communication Technology Department

Interviewer – Good afternoon, let's begin with a brief introduction to your department.

We are solely responsible for IT infrastructure, networks and the maintenance of databases used by NCEMA and some of their partners. We are expected to use the best available technologies for these systems. So we regularly assess emerging technologies in ICT. We also study how other nations use new ICT technologies so that we can maximise their use.

Interviewer - Thanks for that. What are your interactions with the national framework?

We use the national framework to identify structures, policies, and operations of the stakeholders so that we can identify the best ICT solutions. Of course, we have regular interactions with stakeholders to ensure that we meet their ICT requirements.

One of our crucially important projects was the establishment of a special database for coordination and continuity during emergencies. This database provides up-to-date information to decision-makers and those who are dealing with the recovery. This has contributed to the successful management of several emergencies in the past. So, we play a critical role in ensuring that stakeholders can execute plans provided by the national framework.

Interviewer – Thanks, any other specific technologies that you use?

As said before our focus is very much on ICT.

Interviewer – are there any technologies out there you wish to explore?

As you may be aware, AI is becoming a hot topic in general. So, we would like to explore the potential use of AI within ICT. We don't know much about the use of AI in emergency management, but I suspect there will be opportunities in the future.

Stage 6: Reporting the findings

Step 1: Identifying the appropriate qualitative data analysis technique

Saunders et al. (2009) present a range of techniques for qualitative data analysis which are summarised in the (table 4.3).

Technique	Description
Discourse Analysis	Uses the language presented in data to draw meaning
Grounded Theory	Generation of theory from collated data
Narrative Analysis	Generation of stories (narratives) from collated data or observations
Template Analysis	A specific version of thematic analysis which use a hierarchy of codes
Thematic Analysis	Identifying patterns within collated data using codes

Table 4.3 : Techniques for qualitative data analysis (Saunders et al., 2009)

As outlined in Table 4.1, interviews aimed to identify (a) strengths (b) potential improvements and (c) technologies used within the context of the UAE emergency management framework. Therefore, the thematic analysis is the most suitable technique for the analysis of qualitative data collected through the interviews.

Step 2: Using Nvivo for thematic analysis

NVivo is a well-known qualitative data analysis platform used by researchers (NVIVo, 2021). It has been widely used to conduct thematic analysis (Castleberry & Nolen, 2018) ,(Judger, 2016). This analysis was conducted using four codes, Strengths, Weaknesses, Opportunities and Threats.

In the following, how NVivo was used to analyse collated information is briefly explained.

Task (a): Upload interview scripts.

Task (b): Set up four (4) key codes, namely Strengths, Weaknesses, Opportunities and Threats.

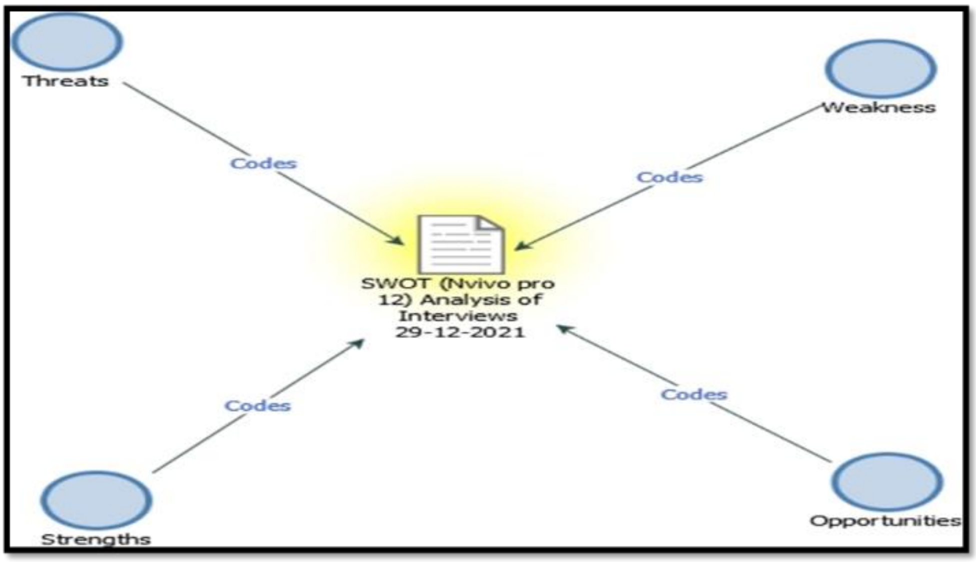


Figure 4.1: Codes Used (Author)

Task (c): Explore the key outputs from the analysis. Two screen shots are show in Figures 4.2 and 4.3.

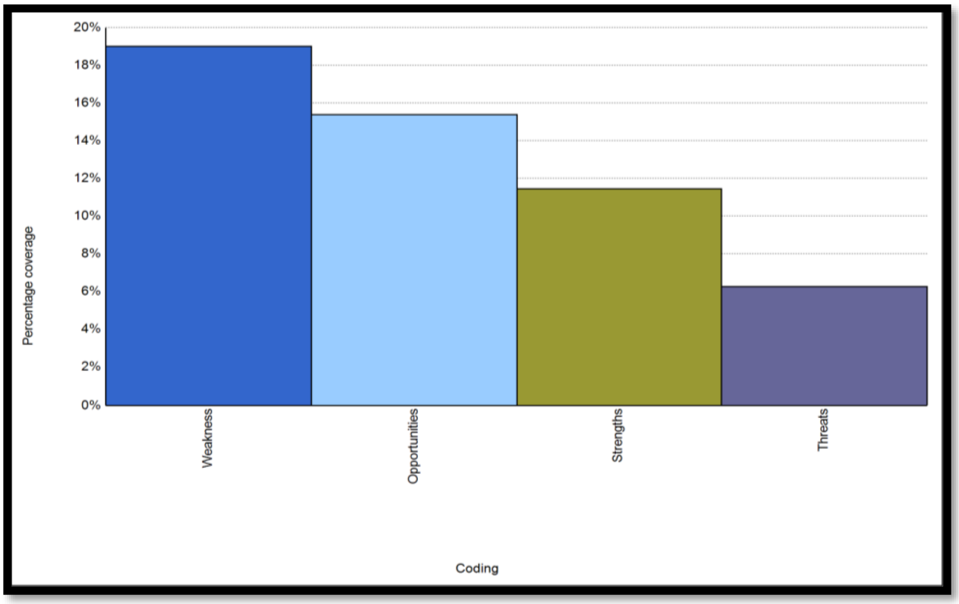


Figure 4.2: Percentage coverage of codes (Author)

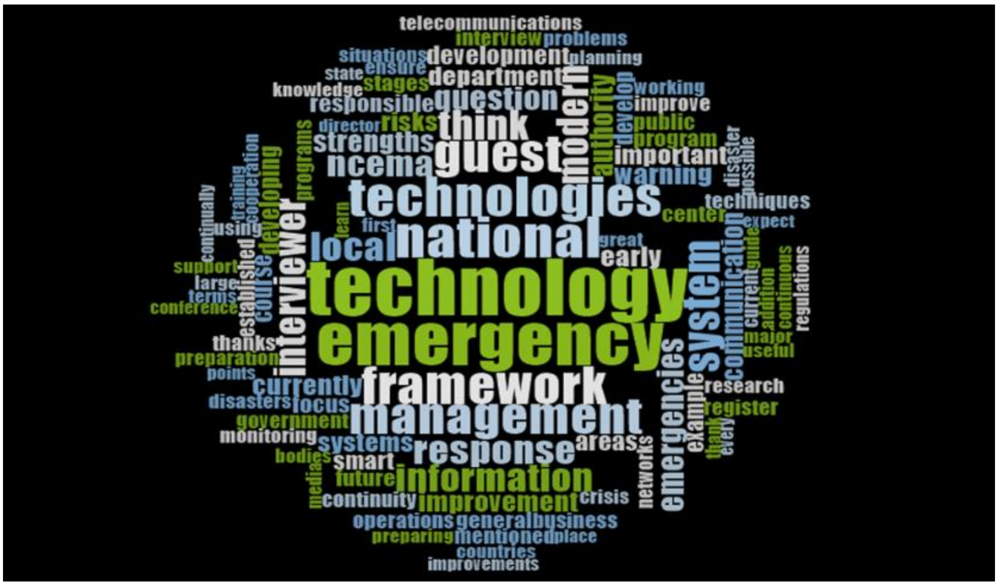


Figure 4.3: Word Cloud (Author)

Task (d): Extract statements that relates to codes to form the SWOT analysis in Step 3.

Step 3: Results from the analysis (SWOT Analysis)

STRENGTHS
• Establishment of a national Framework in 2013 and standardization of laws and regulations between local bodies. • Senior executive team meetings regularly to update and change laws and regulations to ensure that all Emirates are aware of the changes. • Creation a Risk Register. • Establishment of the National Operations Center, in addition to establishing subsidiary operations centers in each emirate affiliated to it. • Establishment of a training center for emergency management, agreements and international cooperation. • Coordinating and developing an integrated response system in cooperation with local teams and implementing it on several occasions through joint exercises. • Creation of a database for coordination and continuity during emergencies that provides up-to-date information for decision makers and agencies dealing with the recovery phase.
WEAKNESSES

- The slow development of modern systems and technologies due to lack of knowledge.
- Lack of awareness and knowledge of modern technologies.
- The public and society's lack of awareness of the importance of emergency management
- The inadequacy of the early warning system and warning text messages with many of the phone technologies used in the country.
- The inability of visitors to the country to benefit from the early warning system due to the difficulty of programming the systems with those phones.
- The lack of a specialized work team to research and monitor the development of modern technologies.
- The absence of a clear and well-studied strategic and methodological plan to determine the use of new technologies in emergency management.
- Need to improve and develop guidelines for simulations and training in emergencies

OPPORTUNITIES

- Develop an Early Warning System (EWS) to send early warnings to all mobile phone users via SMS and social media platforms
- Use visual business intelligence tools to update management information systems to support decision-making
- Create a central database to record and analyze all incidents in one place to support decision-making.
- Improving the local scientific knowledge base for emergency management and seeking local universities to take initiatives in this field.

THREATS

- Growing flow of migrant workers due to the rapid growth of the economy
- Overall, the risks are increasing in the UAE.
- The lack of a systematic approach to emergency management which causes more problems.
- The inability to predict the future by not knowing the type of situations and accidents that will occur in the future

Table 4.4 : Results from SWOT Analysis (Author)

Given the above analysis, it is concluded that use of the latest technologies such as Industry 4.0 might give the UAE emergency management community to enhance their processes and approaches.

4.5 Questionnaire Survey

To supplement the interviews and gather views from a wider audience, a questionnaire survey was designed and conducted.

Step 1: Set objectives of the survey

The main objectives of the survey is to establish the perceptions on the following:

(a) types of natural and non-natural disaster that can be expected in the UAE

(b) views on the usability and integration aspects of the UAE National Response Framework

(c) use of technologies

Step 2: Design the questionnaire

With the view to capture information relating to the above objectives, a questionnaire with 15 questions, organised in five (5) sections, was developed. An open-ended question was added to capture any suggestions for improving the UAE National Response Framework.

Appendix 1 includes the details of the questionnaire (final version).

Step 3: Pilot test of the questionnaire

The first version of the questionnaire was reviewed with three (3) senior managers from the Dubai Police and NCEMA. These reviewers advised that the questionnaire should not include any questions on their specific roles as they may deter providing unbiased views. As a result of this feedback the first section of the questionnaire was re-designed to capture a more generic view on the profile of individuals.

Step 4: Conduct the survey

The questionnaire was delivered in two formats: web-based (Google form) and paper-based. A total of 152 participants from different organisations such as the Dubai Police, NCEMA and emergency services were approached. Data was collected over a period of 4 months.

Step 5: Analyse survey data

A total of 73 responses were received from the survey participants, i.e., 48% response rate. Although a higher response rate is desirable, 48% response rate is considered as acceptable.

In the following, the same question identification numbers are used for easy cross referencing.

Q1.1 The level of understanding of the UAE National Response Framework

Level of understanding	No. of responses	% of responses
High	41	56%
Medium	22	30%
Low	10	14%
Total	**73**	**100%**

Table 4.6: The level of understanding of the UAE National Response Framework (Author)

The reliability of these responses may not be accurate as the choices are not measurable; they are subjected to personal judgment. Based on a smaller sample, where the research has some interactions with the Dubai Police and MENA, it can be reasonably concluded that a significant proportion has a good understanding of the framework.

Q1.2 For how many years you have associated with the framework?

No years	No. of responses	% of responses
1-2 years	33	45%
3-5 years	36	49%
5 years +	4	6%
Total	**73**	**100%**

Table 4.7: Years of association with the national framework (Author)

The UAE National Response Framework was formally launched in 2013. The survey was conducted in 2018. Four (4) participants have more than 5 years of experience. It is likely these four (4) participants were involved in developing the framework.

q1.3 What is your association with the National Response Framework?

Type of Association	No. of responses	% Responses
Contributor (contributes to the development and/or review of the framework)	8	10%
Enforcer (ensures others fully understand the framework)	19	26%
Coordinator (implementation of the framework in the event of a disaster)	30	42%
User (potential user of the guidance provided by the framework in the event of a disaster)	16	21%

Other (Please specify)	0	0%
Total	73	100%

Table 4.8: Areas of engagement (author)

This sample of 73, includes representatives from all areas of engagement. It was good to capture responses from a broad spectrum of stakeholders.

Q1.4 What is the role of your organisation in the event of a major disaster?

Type of organisation	No responses	% Responses
Frontline operations - dealing with the victims of the disaster	27	37%
Coordination of frontline operations	26	36%
Coordination at higher levels of the government	20	27%
Total	73	100%

Table 4.9: Type of organization (Author)

All types of organisations are represented in the sample.

Q2.1 What level of risk from <u>natural</u> hazards do the UAE face?

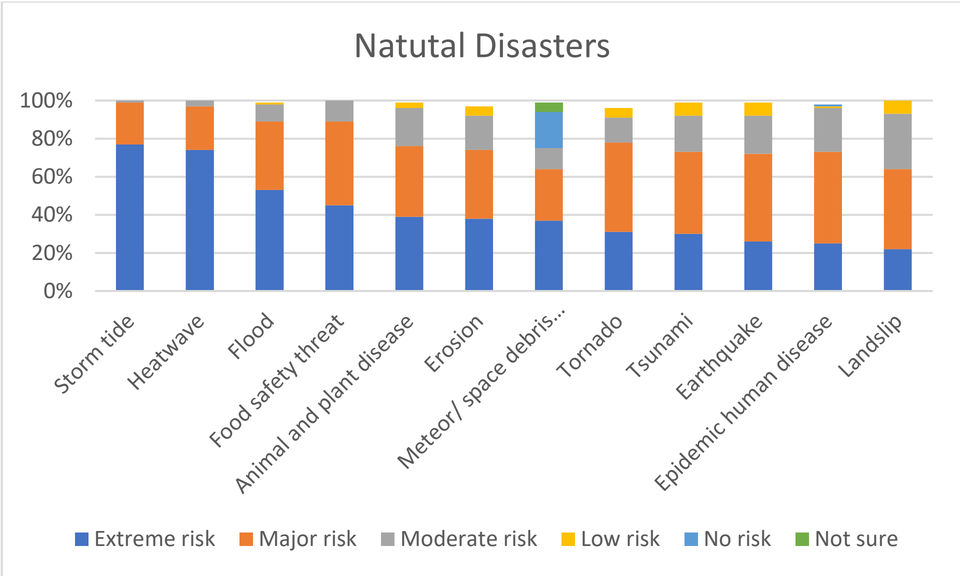


Figure 4.4: Natural Disasters in the UAE (Author)

Dhanhani et al. (2010) identify storm tides and floods as major threats in the UAE. Zittis et al.(2021) predict that the Middle East and North Africa (MENA) region will face intense heat waves in the future. Figure 4.2 shows their predictions. Therefore, it can be concluded that the survey findings tally with the forecast from other sources. If this survey was conducted now (2021), it is very likely that “epidemic human diseases” would be ranked as one of the top natural disasters.

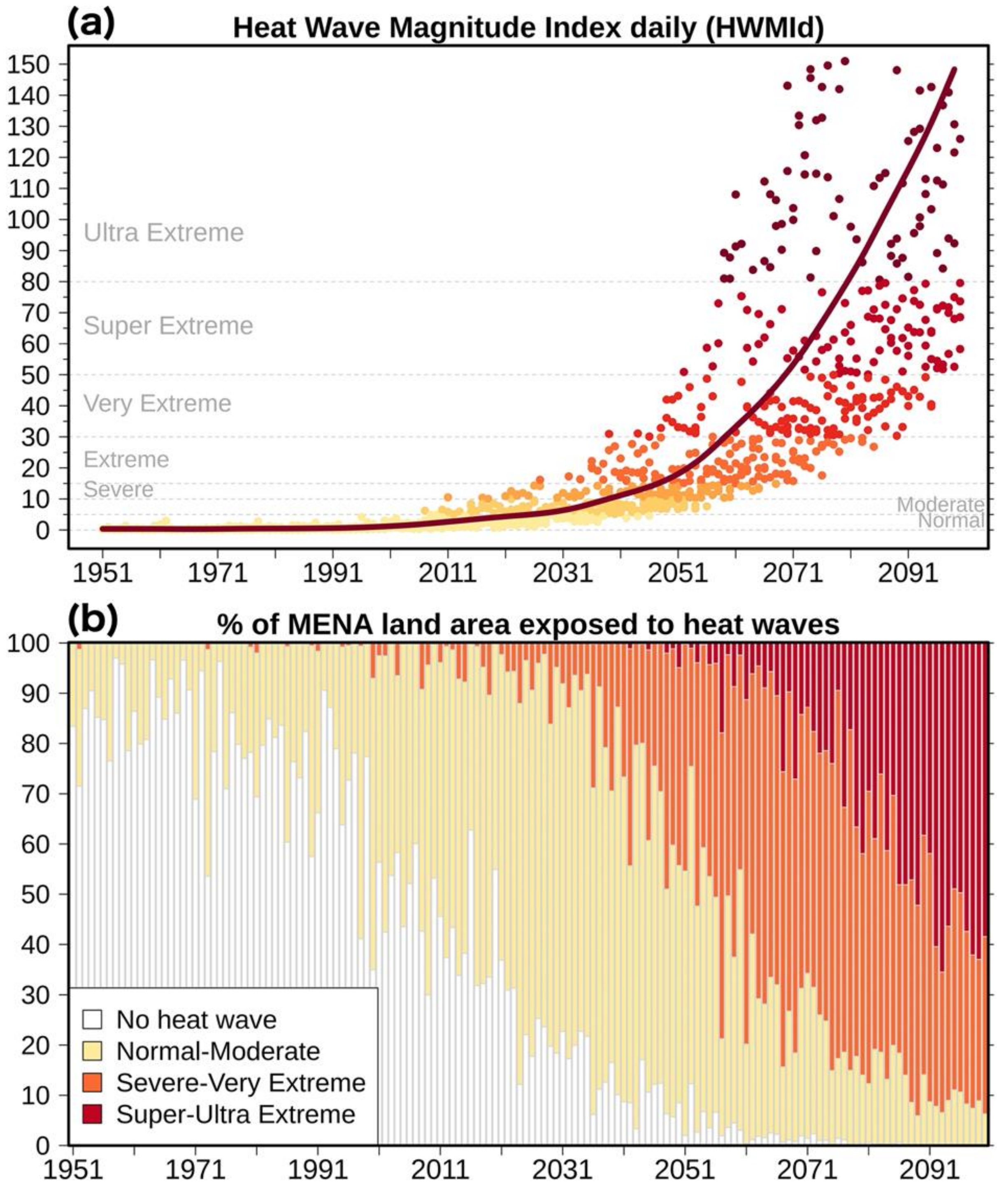


Figure 4.5: Prediction on heatwaves in the MENA region (Zittis et al.2021)

Q2.2 Which <u>non-natural</u> hazards do the UAE face?

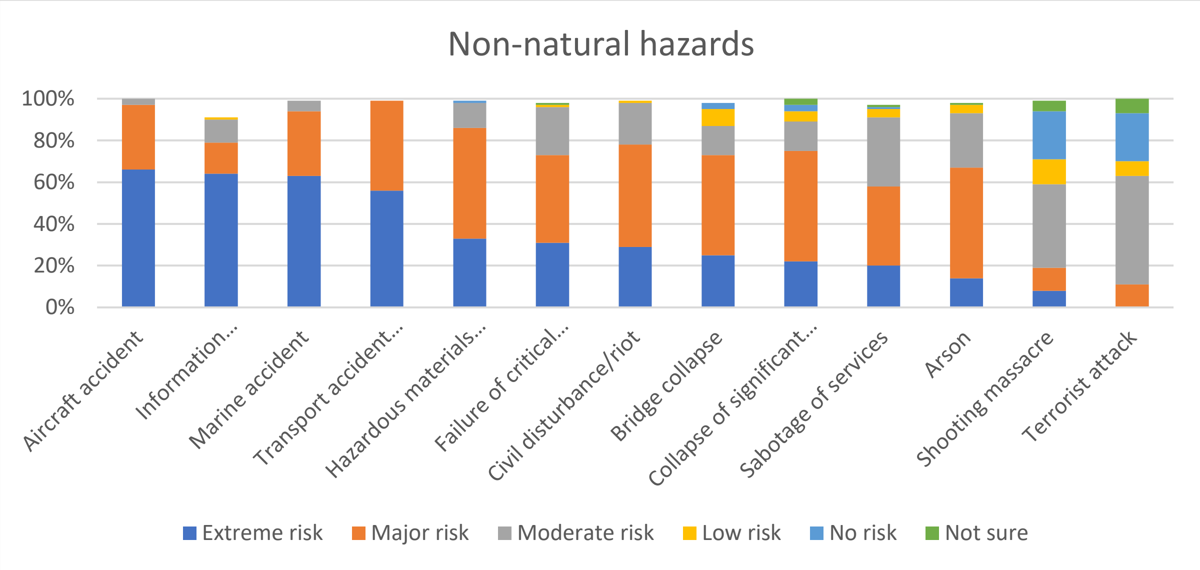


Figure 4.6 Non-natural hazards in the UAE

The UAE is not known for any major incidents involving aircraft; however, more than 60% of respondents ranked aircraft accidents as the highest risk category. Although it is difficult to speculate the reasons behind this view, the rapidly growing air traffic in the UAE may be one of the main reasons. The International Air Transport Association (IATA) predicts that UAE air traffic will grow by 170% in the next two decades.

Q3.1 How do you rate the overall usefulness of the framework?

Overall usefulness	No. of responses	% responses
High	19	26%
Medium	40	55%
Low	14	19%
	73	100%

Table 4.10: Usefulness of the National Response Framework (Author)

Only a quarter of respondents agreed that the National Response Framework is highly useful. This implies that there are opportunities for improvement.

Q3.2 **How would you rate the information available to emergency management activities in these categories?**

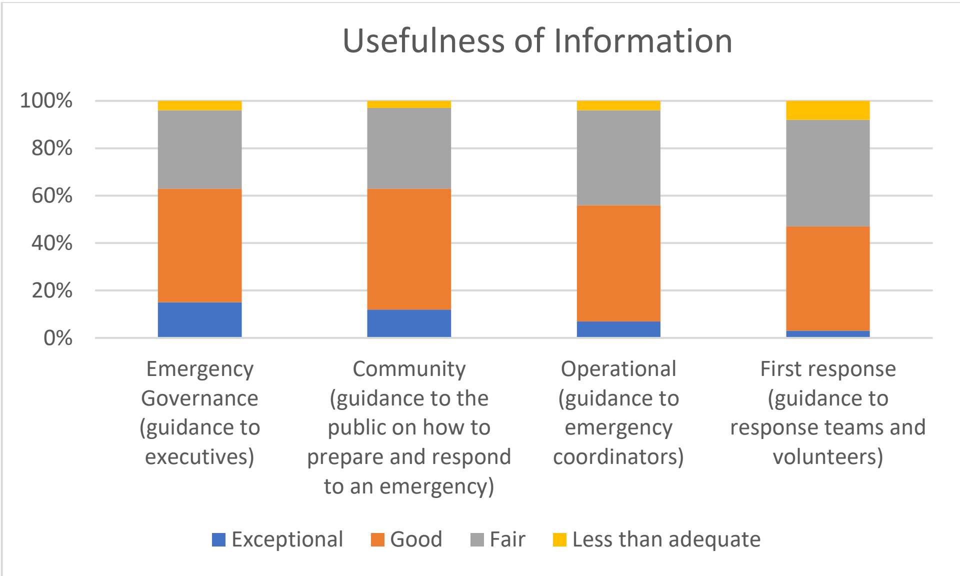


Figure 4.7: The usefulness of information (Author)

If Exceptional and Good categories are considered collectively, there are no significant differences between the first three groups (executives, public, coordinators). However, the first responders are concerned about the usefulness of the information provided in the national framework.

3.3 How important are these sources of guidance on emergency management?

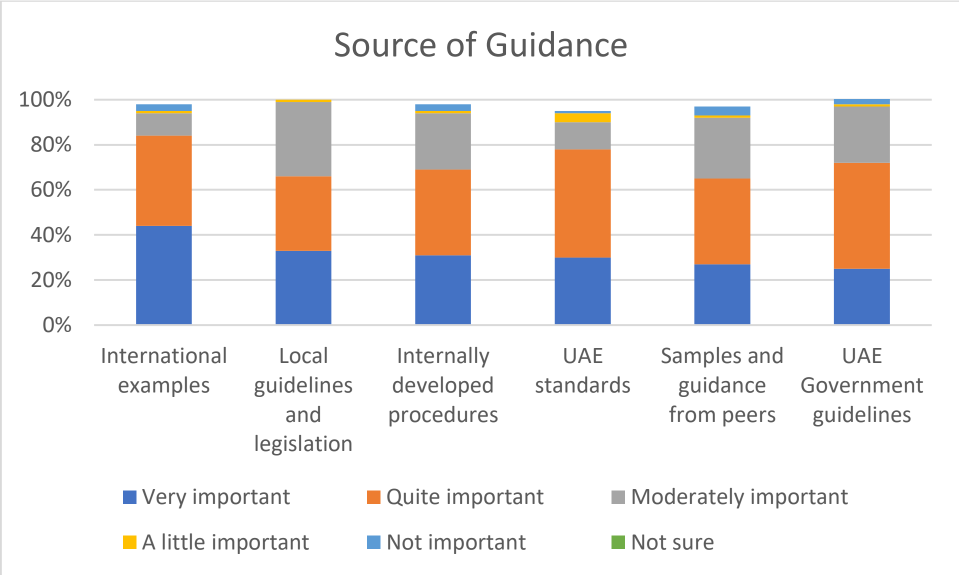


Figure 4.8: Importance of the guidance provided in the framework (Author)

There is an overwhelming desire to learn from the experiences of other nations. Building a knowledge management system that includes examples from other countries will be beneficial.

Q3.4. Effective emergency response requires tighter and effective <u>integration</u> between coordinating departments. How do you rate the information provided on the importance of integration in the framework?

Information on integration	No of Responses	% Responses
Exceptional	4	5%
Good	27	37%
Fair	42	58%
Less than adequate	0	0
Total	73	100%

Table 4.11: Level of integration identified in the national framework (Author)

The information on integration/coordination appears to be somewhat weak. This needs to be considered in the development of the framework.

Q4.1 Science and technology capabilities are essential for enabling the delivery and continuous improvement of national preparedness. How do you rate the UAE efforts to use of science and technology in improving national preparedness?

Use of Science and Technology	No. of Responses	% Responses
Exceptional	67	91%
Good	2	3%
Fair	4	6%
Less than adequate	0	0%
Total	73	100%

Table 4.12: Use of science and technology (Author)

There is unanimous agreement on this i.e. nearly all respondents agree that efforts are being made to use science and technology for continuous improvements.

Q4.2 The following science and technology capabilities may be used to improve national preparedness. How do you rate the importance of the technologies listed below?

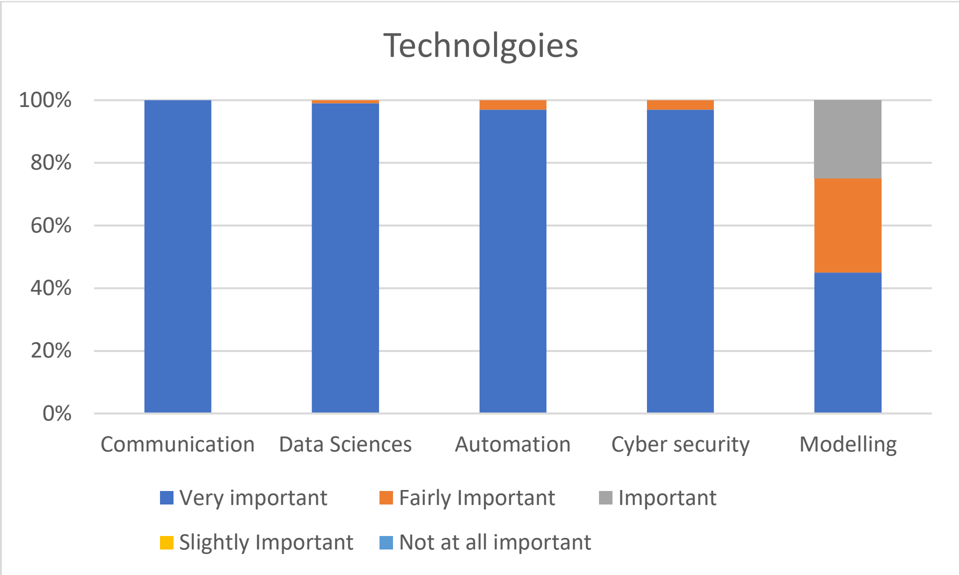


Figure: 4.9: Use of technologies (Author)

Again there is a unanimous agreement on the use of the first four technologies. The lower ranking for modelling may be due to the fact it is the least known technology in general.

Q4.3 Social media plays an increasing role in how people communicate during major incidents. However, any fake news during these incidents could hamper rescue efforts. How do you rate the following statements?

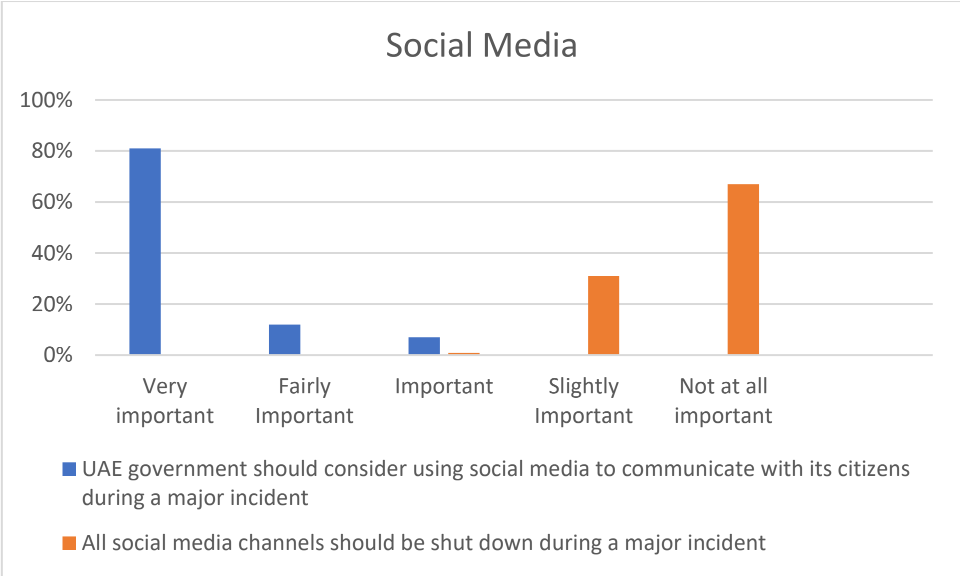


Figure 4.10: Use of social media (Author)

This was a supplementary question to assess how social media technologies should be used during major emergencies. As outlined in the interviews, a social media platform has been designed to communicate key messages to the public,

4.6 Conclusions from primary data analysis

The following conclusions were drawn from the above analysis.

(a) The likelihood of natural and man-made disasters in the UAE is expected to rise.

(b) The National Response Framework provides useful information, but there are opportunities for improvements, particularly in the area of integration.

(c) Science and technology are seen as important assets in dealing with emergencies.

(d) There is an overwhelming desire learn to from previous experiences; some form of knowledge management system would be helpful.

(e) The level of awareness of Industry 4.0 in the emergency community appears to below.

(f) At present ICT and GIS are the main technologies used. Robots and UAVs have been used in some instances

From the evidence gathered from the interviews, the following map (Figure 4.8) shows how technologies are used across the different phases of the emergency management cycle.

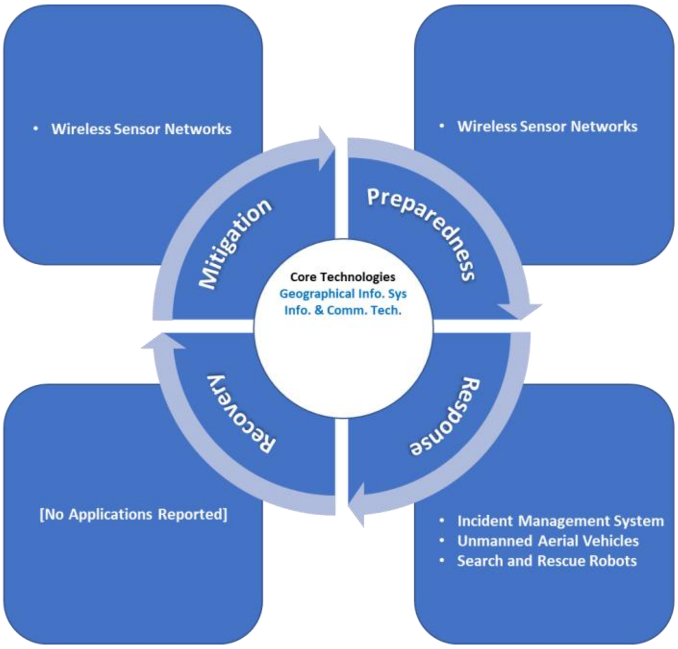


Figure 4. 11: Current Technology Map

The aim of this research programme is to develop a framework to transform the current technology map into a future technology map using Industry 4.0 technologies.

Chapter 5 – Design and Development of the I4EM Framework

5.1 Introduction

As pointed out in chapters 2 and 4, there is a need to develop a structured approach to integrating Industry 4.0 technologies into the UAE Emergency Management framework. A holistic approach is required to ensure that (a) the appropriateness of emerging technologies is systematically analysed and (b) their integration is carefully managed to achieve long-term sustainability.

This chapter therefore focuses on the design and development of the framework, named **I4EM** (Industry 4.0 for Emergency Management). A summary of findings from the literature review, the questionnaire survey and the interviews are presented primarily to outline the gaps and needs of the UAE Emergency Management Framework. As this research appears to be the first of its kind, lessons learned from Industry 4.0 deployments in other sectors are analysed to identify probable implementation pitfalls and strategies to avoid those pitfalls. This chapter then proceeds to identify potential building blocks of the proposed framework. Lastly, the selected building blocks are assembled to create the framework.

5.2 Observations of the previous chapters

The purpose of this section is to summarise key observations from work reported in the previous chapters. These observations support the need for building a framework for the integration of Industry 4.0 technologies.

(a) Chapter 2 – Literature review

The comprehensive literature survey led to the following major conclusions:

(i) Although there are few variations, the four-phase model (mitigation-preparedness-response-recovery) is recognised as the de-facto model in emergency management.

(ii) Several studies have recognised the potential role of Industry 4.0 technologies in emergency management. However, to date a very little attempt has been made to develop a systematic approach to integrate them in emergency management cycles.

(iii) Research work on the UAE Emergency Management Framework is limited. A few studies have however identified the need for further improvements.

(iv) There is an opportunity to enhance the decision-making processes by integrating knowledge management in emergency management cycle.

(b) Chapter 4 – Interviews and the Survey

Due to the limited research on the UAE Emergency Framework, a series of interviews and a questionnaire survey were conducted to gather views from a range of stakeholders. The analysis of this collated data led to the following conclusions:

(i) Senior stakeholders have taken steps to introduce some new technologies, which have been carried out in isolation.

(ii) Senior stakeholders acknowledged that the integration of new technologies can significantly improve the UAE Emergency Management framework.

(iii) There is a lack of understanding of Industry 4.0 in the emergency management community in the UAE.

(iv) The emergency management community welcome the development of a structured framework which facilitates a systematic integration of new technologies.

The above observations strongly support the development of the framework to integrate Industry 4.0 technologies in emergency management.

5.3 Design Principles – I4EM Framework

Within the context of emergency management, frameworks have been built for different purposes. Bhanumurthy et al. (2015), for example, presents a framework integration of geospatial technologies for emergency management. This framework outlines the different technologies used, their components and functions, which are presented in a simple table. Sujanto et al. (2008) present an integrated framework for comprehensive, collaborative emergency management that uses a simple flow chart to depict the building blocks of the framework. Curnin et al. (2015) has developed a framework for negotiating the path of emergency management multi-agency coordination. This framework is also presented by a collection of building blocks (boxes) and interactions between them (arrows). Visual diagrams are the backbone of the framework, and details can be added to explain the functionalities of building blocks and the interactions between them.

The most important step in the development of the framework is the identification of the building blocks required to formulate the framework. Within the context of the I4EM Framework, the following aspects are used to identify the required building block:

(a) Mapping of Industry 4.0 technologies to the emergency management cycle.

(b) Implementation challenges of Industry 4.0 and digital transformation, focusing on readiness models.

(c) Gaps identified in the literature review.

(d) Needs identified by the emergency management community in the UAE.

(e) Future opportunities in the post Industry 4.0 era.

The following diagrams summarise the generation of the building blocks.

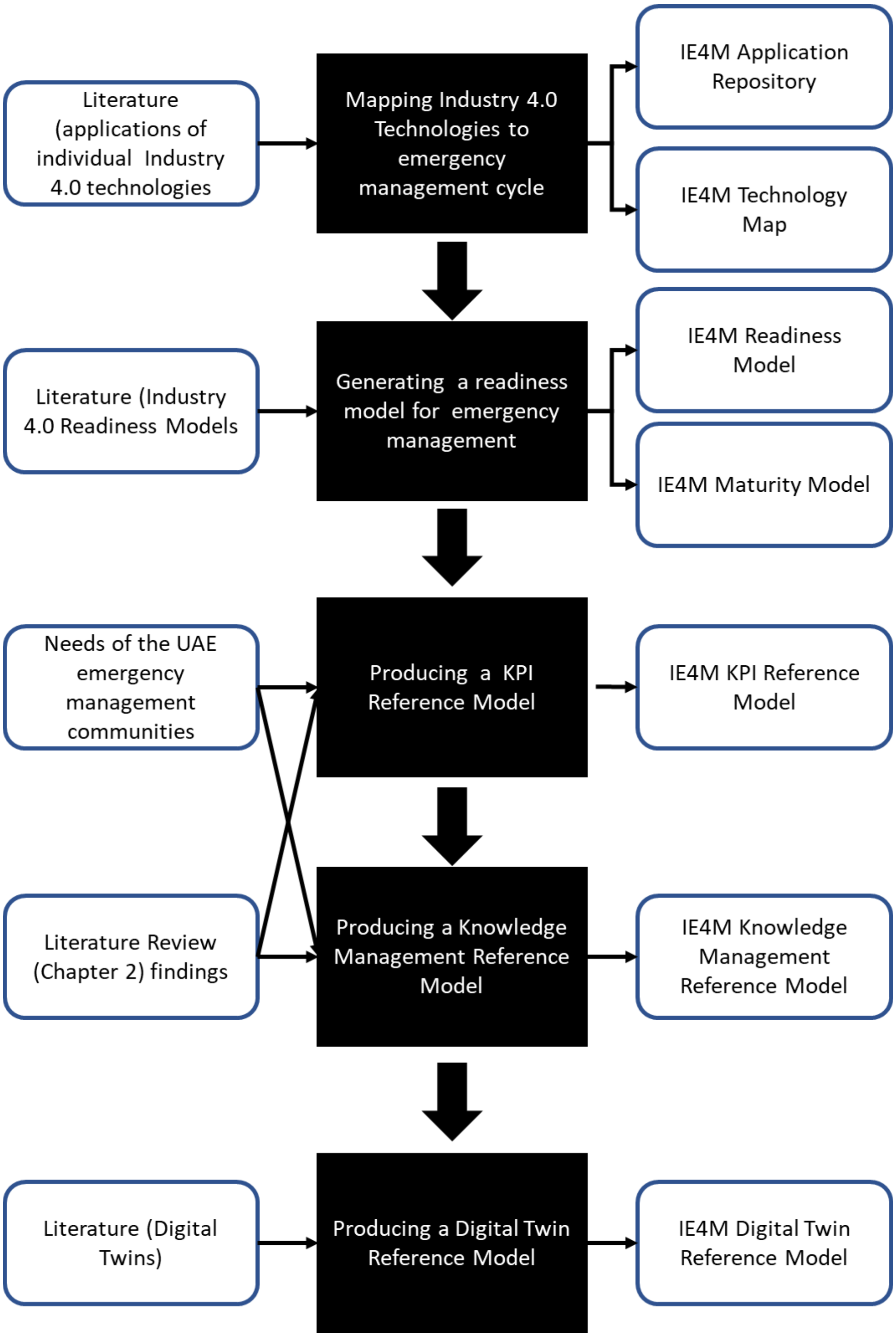


Figure 5.1: Generating the modules of I4EM Reference Framework

5.4 Mapping Industry 4.0 Technologies to emergency management cycle

As discussed in Chapter 2, the four-phase (mitigation-preparedness-response-recovery) emergency management model is considered as de-facto standard. As an essential element of the framework development process, it is necessary to develop a comprehensive understanding of where Industry 4.0 technologies can be used within the four-phase model. This can be best achieved by developing a technology map that shows the linkage between Industry 4.0 technologies and four phases of the emergency management model.

5.4.1 Industry 4.0 Technologies

As presented in Chapter 2, Industry 4.0 framework offers nine (9) key technologies. They are presented here again to maintain the continuity within this Chapter.

Technology	Description
Additive Manufacturing	Commonly known as 3D printing, it is a computer controlled process in which objects are created by depositing layers of material.
Augmented Reality	Creates experience of a real world environment using computer generated perceptual information.
Autonomous Robots	Robots with a high degree of autonomy which is built on artificial intelligence and sensor technologies.
Big Data	Technologies for analysing very large volumes of data typically involving different types data (images, ie Data – technologies for analysing very large volumes of data typically involving different data types (images, social-media and voice etc) and real-time data, for example, sourcing from sensors, social-media and voice etc) and real-time data, for example, sourcing from sensors.
Cloud Computing	Refers to the delivery of computing services over the Internet.

Cyber-security	Technologies developed to protect computer systems and networks from the theft of information and/or damage to hardware.
Internet of Things	Internet connected devices which can transfer information between them without any human interaction.
Simulation	Modelling technologies to create computer models of proposed or real systems.
Systems Integration	Technologies developed to integrate different systems to create whole systems.

Table 5.1 : Industry 4.0 Technologies (Author)

These technologies collectively assist in creating “digital twins” which can be used to continually improve the operations of the systems under investigation. The potential use of digital twins needs to be considered within the development of the framework.

5.4.2 Use of Industry 4.0 Technologies in Emergency Management

Although to date, no attempt has been made to develop a systematic approach to integrating Industry 4.0 technologies in emergency management, there are examples of where individual technologies have been used in emergency management. A comprehensive analysis of literature was conducted to identify applications. The tables below present a selection of examples:

Additive Manufacturing			
Code	Author(s)	Application	Emergency Management Phase
AM1	Rodríguez-Espíndola & Beltagui (2018).	Production of tools (for example, masks, shovels) required for response and recovery activities. The production of blankets, clothing and shoes. Production of relief-package items such as plates and cups. Production of transitional shelters.	Response Recovery Recovery Recovery Recovery
AM2	Saripalle et al. (2016)	Production of medical disposables, prosthetic limbs and utensils.	Recovery
AM3	Gregory et al .(2016)	Production of shelters.	Recovery
AM4	Chu et al. (2015)	Sensor-smart Affordable Autonomous Robotic Platforms (SAARP) project – The SAARP Store contains a library of robots. The system allows the user to select, print, assemble, and operate the robot.	Response
AM5	Dotz (2015)	3D printing of medical devices (Haiti Disaster).	Response

Table 5.2: Additive Manufacturing Applications (Author)

Augmented Reality (AR)			
Code	Author(s)	Application	Emergency Management Phase
AR1	Brunetti et al. (2015)	SAFE (Smart Augmented Field for Emergency) for training teams of rescuers. SAFE is based on the integration of wearable computing and augmented reality technologies.	Prepare
AR2	Nun et al. (2017)	THEMIS (distributed Holistic Emergency Management Intelligent System) – uses augmented reality technologies to visualise data enabling teams to develop a holistic view of the disaster.	Response
AR3	Leebmann, (2004).	This Augmented Reality based system overlays different invisible disaster-relevant information (humans hidden by debris, simulations of damages and measures) on the image of reality.	Response
AR4	Mitsuhara et al. (2016)	Using Augmented Reality in game based evacuation drills.	Prepare
AR5	Zhu et al. (2021)	Augmented reality technology based for emergency management in the built environments. Applications include: • Hazard recognition, Training • Human evaluation • Damage detection	Prepare Response Recovery

Table 5.3: Augmented Reality Applications (Author)

Autonomous Robots (ARo)			
Code	Author(s)	Application	Emergency Management Phase
ARo1	Sakr et al. (2016)	Using Unmanned Aerial Vehicles (UAVs) as a platform to collect geospatial data for rapid response applications.	Response
ARo2	Kuntze et al. (2012)	An integrated system involving robots and sensor systems to make the search and rescue quick and efficient.	Response
ARo3	Lou et al. (2018)	A range of applications using UAV systems. Early warning systems. Data gathering. Supply chain.	Mitigation/Response Response Response Recovery
ARo4	Munawar et al. (2021)	Flood detection using data gathered from UAVs>	Mitigate Prepare

Table 5.4: Autonomous Robot Applications

Big Data (BD)			
Code	Author(s)	Application	Emergency Management Phase
BD1	Murakami et al. (2015)	Higher resolution prediction model using predictive analytics for forecasting meteorological events, including tropical cyclones, hurricanes, and winter storms.	Mitigate Prepare
BD2	San-Miguel-Ayanz et al .(2012)	Using spatial and temporal data with Big Data analytics for disaster monitoring and detection.	Prepare
BD3	Liou et al. (2010)	Using remote sensing imagery and big data techniques to assess damage.	Response
BD4	Van de Walle et al. (2012)	Use of big data analytics to produce more accurate information from data gathered from different sources such UN inter-agency OneResponse website, the Sahana Free and Open Source Disaster Management System, and the crowdsourcing platform.	Response
BD5	Contreras et al. (2017)	Measuring the progress of recovery efforts progressively (every two years) after the earthquake at L'Aquila, Italy in 2009.	Recovery

Table 5.5: Big Data Applications

Cyber Security (CS)			
Code	Author(s)	Application	Emergency Management Phase
CS1	Panesir (2018)	Improving information security during disasters with special reference to national security.	Response Recovery
C2	Aranda et al .(2019)	Using IoT and Blockchain to increase humanitarian aid supply chains performance.	Response Recovery

Table 5.6: Cyber Security Applications (Author)

Simulation (SM)			
Code	Author(s)	Application	Emergency Management Phase
SM1	Dimakis et al . (2010)	Building evacuation simulator for emergency management.	Prepare
SM2	Farra et al. (2019)	Simulation based training for evaluation and disaster relief methods.	Prepare

Table 5.7: Simulation Applications

Internet of Things (IoT)

Wireless sensor networks have been the means of gathering data which may help to predict upcoming disasters (Lorincz et al. 2004). For example, seismological data is used to predict the occurrence of earthquakes (ur Rahman et al. 2016). However, with the invention of IoT, traditional wireless networks are being replaced by IoT enabled networks (Krytska, Skarga-Bandurova & Velykzhanin, 2017). Given their widespread use, IoT technologies and networks can be used in every phase of the emergency management cycle.

Cloud Computing (CC)
Like IoT, Cloud Computing is also rapidly becoming the platform of choice for many applications (Qiu, 2014). Given the lower hardware costs and the ability to access data and applications via the internet make Cloud Computing the preferred platform for emergency management.

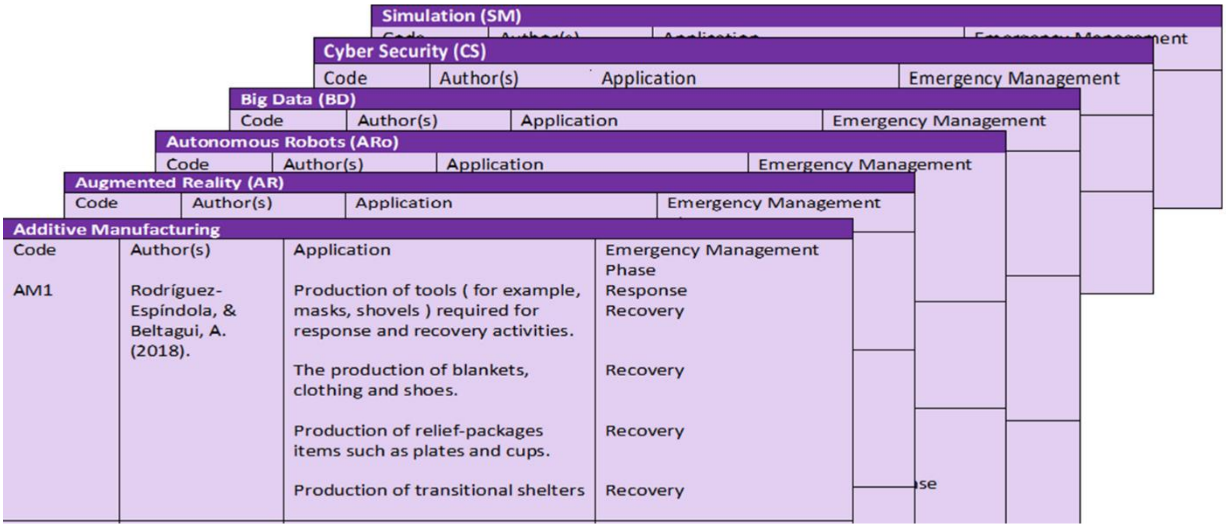
Systems Integration (SI)
Connected systems should be the backbone of any IT system. Given the range of stakeholders involved in emergency management, systems integration is seen as a central pillar of any development. It plays a critical role in avoiding the proliferation of disconnected systems which lowers the responsiveness and effectiveness [References].

5.4.3 I4EM Application Repository and I4EM Technology Map

The analysis conducted in the above section produced two building blocks for the I4EM framework:

(a) I4EM Application Repository

The tables produced above collectively generated the I4EM Repository as shown in the (Table 5.7)This is a live repository which needs to be kept updated as new applications/research emerge.



Additive Manufacturing			
Code	Author(s)	Application	Emergency Management Phase
AM1	Rodríguez-Espíndola, & Beltagui, A. (2018).	Production of tools (for example, masks, shovels) required for response and recovery activities.	Response Recovery
		The production of blankets, clothing and shoes.	Recovery
		Production of relief-packages items such as plates and cups.	Recovery
		Production of transitional shelters	Recovery

Figure 5.2: I4EM Application Repository (Author)

(b) I4EM Technology Map

This technology map shows the application of Industry 4.0 technology against each phase of the emergency management cycle.

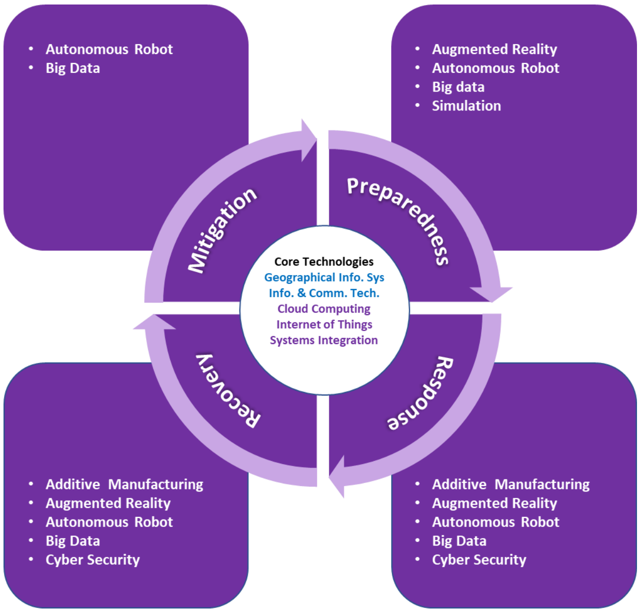


Figure 5.3: I4EM Technology Map

5.5 Generating a readiness model for emergency management

Although several studies have identified the potential use of Industry 4.0 technologies in emergency management, none report any challenges that implementors may experience during the process of deployment. It is vital to have a good understanding of potential implementation issues before the framework is designed, so that they can be taken into consideration during the framework development process.

Given that there is only limited literature available on this specific aspect, i.e., implementation issues of Industry 4.0 in emergency management, the only option is to analyse examples from other sectors and similar technologies. Given that Industry 4.0 has its origins in the manufacturing sector. The first step was to review implementation issues and considerations in that sector. To strengthen this analysis, the study was extended to include examples from “digital transformation” projects in general. As reported by several authors (Adamik & Nowicki (2018), Lee, et al. (2017), Rajnai & Kocsis (2018)), Industry 4.0 complements digital transformation.

5.5.1 Industry 4.0 implementation issues and solutions

Based on a survey of manufacturing organisations, a report by CapGemini Research Institute (CapGemini (2019)) identifies three (3) key challenges in deploying Industry 4.0 technologies.

- Lack of readiness in deploying and integrating Industry 4.0 technologies (5.4.1.1)
- Inadequate data readiness and cybersecurity measures (5.4.1.3)
- Lack of digital skills for industry 4.0 implementations (5.4.1.4)

Several other studies have also identified them as key challenges Xu, David & Kim (2018), Stentoft, (2020), Macurová, Ludvík & Žwaková (2017)) . In the following, these three (3) challenges are discussed in details and a selected number of solutions proposed by research teams and professional bodies are presented.

5.5.1.1 Lack of readiness in deploying and integrating Industry 4.0 technologies

A key characteristic of industrial revolutions is that they should lead to a "radical" transformation (Melnyk, 2019). The term "radical" means a fundamental change. Therefore, one of the obvious questions is whether organisations are ready for a fundamental change. Given that Industry 4.0 is the 4th industrial revolution, the readiness for Industry 4.0 has been a subject of interest for research communities, professional bodies, and governmental organisations. These efforts have produced a range of "Industry 4.0 Readiness Maturity Models" [Çınar, Zeeshan & Korhan (2021). Each maturity model consists of "dimensions" which will decide the level of maturity. The number of maturity levels varies from model to model.

Çınar, Zeeshan & Korhan (2021) reports a comparison of maturity models. As shown (Table 5.8), the authors have used six (6) parameters to compare.

Maturity Model	Score	Fitness for purpose	Completeness	Dimension of Granularity	Measurement Attribute	Complete Method	Objectivity
The Connected Enterprise	1	N-A	P-A	N-A	N-A	N-A	N-A
IMPULS	10	P-A	P-A	P-A	L-A	F-A	L-A
RAMI 4.0	9	L-A	P-A	L-A	N-A	F-A	L-A
Digital Maturity	7	P-A	L-A	P-A	P-A	P-A	P-A
I4.0 Reifegradmodell	9	P-A	P-A	P-A	L-A	F-A	L-A
I4.0 Empowerment and Implementation Stg.	0	N-A	N-A	N-A	N-A	N-A	N-A
MM for Industrial Network	0	N-A	N-A	N-A	N-A	N-A	N-A
A categorical Framework of Manufacturing	0	N-A	N-A	N-A	N-A	N-A	N-A
I4.0/Digital operations Self-Assessment	5	P-A	P-A	P-A	P-A	N-A	P-A
SIMMI 4.0	7	P-A	P-A	P-A	P-A	L-A	P-A
MM for Assessing I4.0 Readiness/Maturity	6	P-A	P-A	P-A	P-A	P-A	P-A
ACATECH I4.0 Maturity Index	3	P-A	P-A	N-A	N-A	N-A	P-A
SPICE-based MM	11	P-A	L-A	L-A	P-A	F-A	L-A
DREAMY MM	5	P-A	P-A	P-A	P-A	N-A	P-A
WMG MM	10	P-A	P-A	L-A	P-A	F-A	L-A
Maturity and readiness model for I4.0	2	P-A	N-A	N-A	N-A	N-A	N-A

Table 5.8: A comparison of Maturity Models (N-A (not achieved), P-A (partially achieved) , L-A (largely achieved) and F-A (fully achieved)

In order to select the top 3 maturity models, the following scores were allocated:

- N-A (not achieved) – 0
- P-A (partially achieved) -1
- L-A (largely achieved) - 2
- F-A (fully achieved) -3

The top 3 models with the highest scores, SPICE based MM, IMPULS and WMG MM are explored below:

(a) Industry 4.0 Maturity Model (SPICE based Maturity Model)
A team researcher from the Informatics Institute, Middle East Technical University in Turkey has developed this model (Gökalp, Şener & Eren (2017)). As their work was first presented at the International Conference on) **S**oftware **P**rocess **I**mprovement and **C**apability D**e**termination, Authors identified it as SPICE based Maturity Model. The structure of the Industry 4.0 Maturity Model has been formed based on the ISO/IEC 15504 Part 2 and ISO/IEC 15504 Part 5 [ISO/IEC (2012), ISO/IEC (2004)). (Figure 5.4) shows the dimensions and maturity levels.

Figure 5.4 : The structure of Industry 4.0 Maturity Model. (Gökalp, Şener & Eren (2017)).

(b) VDMA IMPULS Model
The initial work to assess the readiness appeared to come from Germany, where the Industry 4.0 concept was developed. In 2015, VDMA, the Mechanical Engineering Industry Association, funded a study to build an assessment tool for readiness towards Industry 4.0 (Lichtblau et al. 2017). VDMA is the largest network for mechanical engineering in Germany and Europe (VDMA ,2021). The main objective of the study was to build a simple and user-friendly system (Lichtblau et al. 2017). Their solution, known as IMPULS, includes six (6) dimensions (Figure 5.5). Each dimension includes several sub-dimensions. There is an online version of the IMPULS available at https://www.industrie40-readiness.de/?lang=en. This study also developed a maturity model (Figure 5.5) with six levels from “outsider (Level 0)” to “Top Performer (Level 5) [Sony & Nail, (2019).

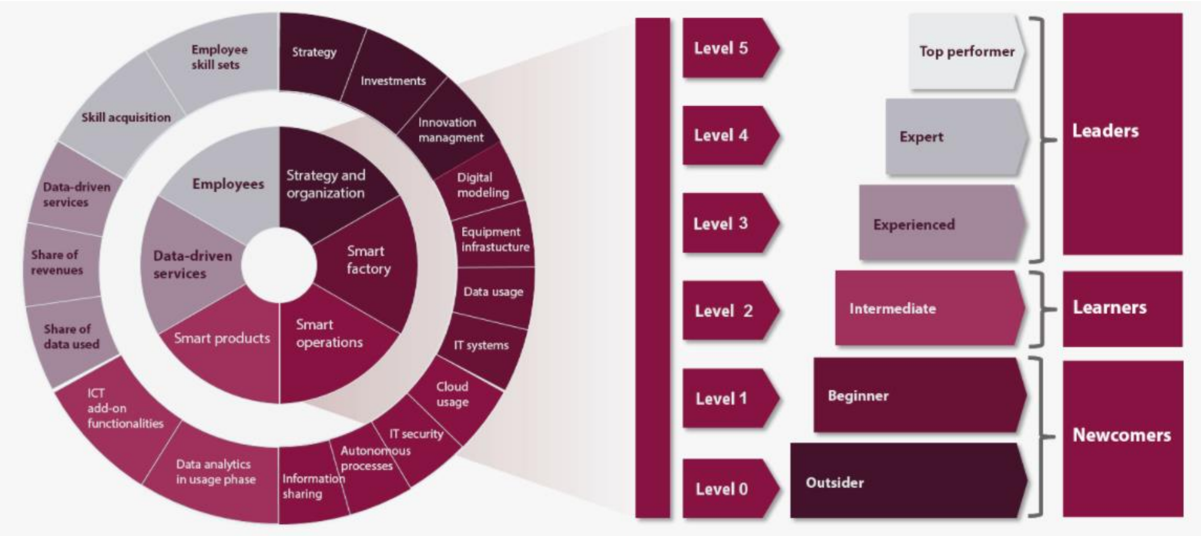


Figure 5.5 : Readiness Assessment dimensions and the Maturity Model – VDMA IMPULS (Source: https://www.industrie40-readiness.de/?lang=en)

(c) Warwick Manufacturing Group Industry 4.0 Readiness Model

In the UK, the Warwick Manufacturing Group in collaboration with Crimson & Co and Pinsent Masons, developed a simple and intuitive way to measure the readiness for industry 4.0 Agca et al. (2017). This readiness model has six dimensions

- Products and services
- Manufacturing and operations
- Strategy and organisation
- Supply chain
- Business model
- Legal considerations

Each of the above dimensions has several sub-dimensions. For example, as shown in (Figure 5.6), the "Business Models" dimension has six (6) sub-dimensions. These sub-dimensions are used to decide the level of maturity, from Beginner (Level 1) to Expert (Level 4).

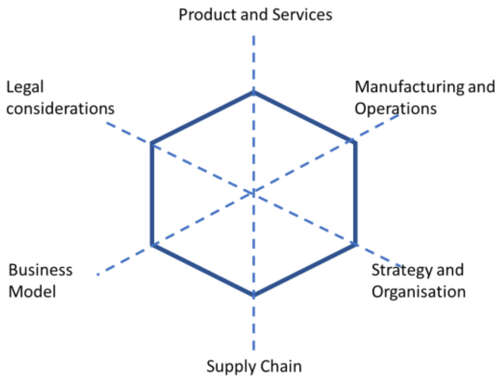


Figure 5.6 : Six dimensions of WMG Industry 4.0 Readiness Model (Agca et al. (2017)

Readiness level	Level 1 Beginner	Level 2 Intermediat e	Level 3 Experienced	Level 4 Expe rt
'As a service' business model	No awareness	Aware of concept with some initial plans for development	High awareness and implementation plans are in development	'As a service' has been implemented and is being offered to the customer
Data driven decisions	Data is not widely analysed	Some data is analysed and features in key business reports to review performance	Most data is analysed and the result is considered when making business decisions	All relevant data is analysed and informs business decisions
Real-time tracking	Limited product tracking	Product can be tracked as it moves between manufacturing and internal distribution sites	Product can be tracked through manufacturing and distribution until it reaches the customers distribution centre	Product can be tracked along the complete lifecycle
Real-time and automated scheduling	Equipment is manually maintained in line with the maintenance schedule	Some machines alert operators of a performance issue which enables them to manually schedule a maintenance task	Some machines are self-diagnosing, automatically passing information to the maintenance scheduling system	Machines are generally self-diagnosing, and the maintenance schedule adjusts itself based on real time data input from the machine
Integrated marketing channels	Online presence is separated from offline channels	Integration within the online and offline channels but not between them	Integrated channels and individualised customer approach	Integrated customer experience management across all channels
IT supportedbusiness	Main business process supported by IT systems	Some areas of the business are supported by IT systems and integrated	Complete IT support of processes but not fully integrated	IT systems support all company processes and are integrated

Table 5. 9: An example of sub-dimensions – WMG Industry 4.0 Readiness Model (Agva et al., 2017)

5.5.1.2 Review of models

The proposed I4EM Framework requires its own Readiness Assessment Model to establish the readiness of organisations responsible for emergency management. Instead of building a Readiness Assessment model from the ground up, it may be possible to re-configure an existing model. In the following, the suitability of the three models presented above are explored.

Model	Strength	Weakness
Industry 4.0 Maturity Model	A generic model which can be used in different sectors (service, manufacturing, ..)	Most of the dimensions in this model are aligned with data and IT aspects. I4EM Framework requires a set of broader dimensions to cover other aspects such as people and skills.
Warwick Manufacturing Group Industry 4.0 Readiness Model	A well-respected model in the manufacturing sector.	It has a broader set of dimensions, but the focus is very much on manufacturing, hence reconfiguring this model for the emergency management sectors is challenging.
VDMA IMPULS Model	A very comprehensive model with a set of generic dimensions.	Smart Factory dimension cannot be used in the context of emergency management.

Table 5.10 – Comparison of Maturity Models (author)

Although the VDMA IMPULS Model has been developed for the manufacturing sector, its dimensions are somewhat generic in nature. Therefore, it was decided to use it as the base model for generating a maturity model for the emergency management sector.

5.5.1.3 Inadequate data readiness and cybersecurity measures

As discussed in Chapter 2, all technologies offered within Industry 4.0 are digital technologies. Implementation of digital technologies naturally leads to (a) the explosion of data and (b) increased data security concerns (Ustundag & Cevikcan, 2017). Raptis, Passarella & Conti (2019). presents a comprehensive review of data management issues in Industry 4.0. Among the key area of concern are; (a) slow data distribution in local and mobile clouds and (b) real-time data security. Both aspects are important in emergency management scenarios.

(a) Slow data distribution in local and mobile clouds

To address the speed issue (a), “Edge Computing” has been recognised as a potential technology (Shi & Dustdar (2016). IBM (2015) defines Edge Computing as:

“a distributed computing framework that brings enterprise applications closer to data sources such as IoT devices or local edge servers. This proximity to data at its source can deliver strong business benefits: faster insights, improved response times and better bandwidth availability.”

Recent research work (Chen & Englund (2018)., d’Oro et al. (2019) have recognised the usefulness of Edge Computing in Emergency Management.

(b) Real-time data security

Since the inception of information management systems, ensuring the security of data has been a key challenge. Over the decades, various technologies have been developed to improve data security [Kitchin (2016), Yang et al. (2015)]. As shown in Figure 5.7, the Cyber Centre, a collaborative project sponsored by the International Association of Chiefs of Police, the National White Collar Crime Centre, and the Police Executive Research Forum, has succinctly summarised past, present and future threats to data security (The International Association of Chiefs of Police, 2015).

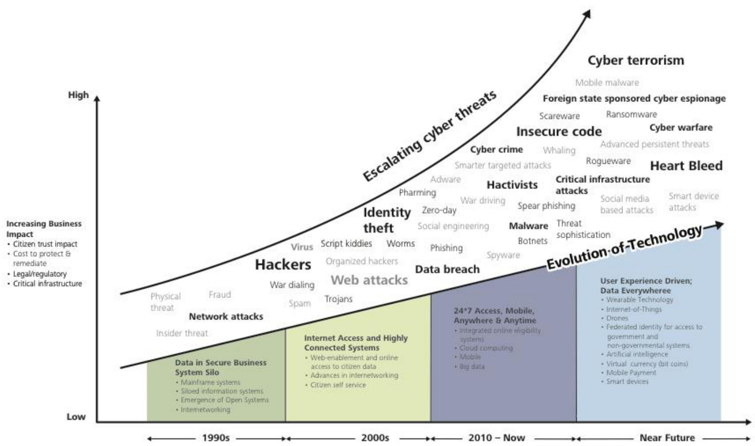


Figure 5.7: Escalating Cyber Threats – Past, present and future (The International Association of Chiefs of Police, 2015)

Industry 4.0 recognises Cyber Security as one of its key components (Thames & Schaefer (2017)., Lezzi, Lazoi & Corallo (2018).]. In recent years, Blockchain Technology has emerged as the leading technology for ensuring data security [Bodkhe et al. (2020), Mohamed & Al-Jaroodi (2019)). Blockchain Technology is, therefore an essential component in the I4EM framework.

5.5.1.4 Lack of digital skills for industry 4.0 implementations

Industry 4.0 presents a very contemporary set of technologies which are designed to revolutionise the way industries operate. Naturally, new technologies mean that those who are involved in the introduction, implementation and use of new technologies are required to acquire new skills. Several studies have taken place to identify skill requirements for Industry 4.0 (Fitsilis, Tsoutsa & Gerogiannis, 2018).

Maisiri, Darwish & Van Dyk (2019) present new technical skills required for Industry 4.0 by analysing a range of publications. Table 5.11 , shows the suggested technical skills required.

Skills category	Skills sub-category	Skills set
Technical skills	Technological skills	• Designing skills that incorporate virtualising, simulating, interoperability, modularising, decentralising capabilities.
		• Fault and error recovery skills
		• Application and use of technological skills
		• Process digitalisation and understanding
		• Ability to work with the Internet of Things,autonomous robots, 3D printing, and other advanced technologies • Interaction with modern interfaces
	Programming skills	• Computational skills
		• Simulation skills
		• Coding
		• Computer and software programming skills • Software development
	Digital skills	• Data analytics/data processing
		• IT/data/cyber security
		• Cloud computing skills
		• IT knowledge and abilities
		• Artificial intelligence skills
		• Digital content creation skills

Table 5.11: . Technical Skill Requirements for Industry 4.0 (Maisiri, Darwish, & Van Dyk, 2019)

It is critically important that all operatives of emergency management systems should have the required skills to ensure the effective deployment of Industry 4.0 technologies. Therefore, learning and development must be a constituent element of the I4EM framework. A recent report by Gartner (Gartner, 2020) argues that the lack of skills might hamper the successful implementation of digital transformation projects.

5.5.2 Digital Transformation implementation issues and solutions

Industry 4.0 is a collection of digital technologies specifically chosen for the manufacturing sector. Some of these technologies have been used in other sectors to support digital transformation even before the industry 4.0 concept emerged Schallmo & Williams (2018). Therefore, it is worth investigating whether any specific barriers have been identified in relation to digital transformation projects. For example (Vogelsang et al., 2019) , present a list of barriers to digital transformation (Table 5.12)

Barrier Scope	**Code**
Missing skills	IT knowledge
	Information about and decision on technologies
	Process knowledge
Technicalbarriers	Dependency on other technologies
	Security (data exchange)
	Current infrastructure
Individualbarriers	Fear of data loss of control
	Fear of transparency /acceptance
	Fear of job loss
Organisationaland cultural barriers	Keeping traditional roles/principles
	No clear vision/ strategy
	Resistance to cultural change / mistake culture
	Risk aversion
	Lack of financial resources
	Lack of time
Environmental barriers	Lack of standards
	Lack of laws

Table 5.12 : Implementation Barriers ((Vogelsang et al. 2019)

Following a comprehensive review of literature (Jones, Hutcheson & Camba, 2021) presents a summary of the top 3 barriers identified from six other recent publications (Figure 5.8)

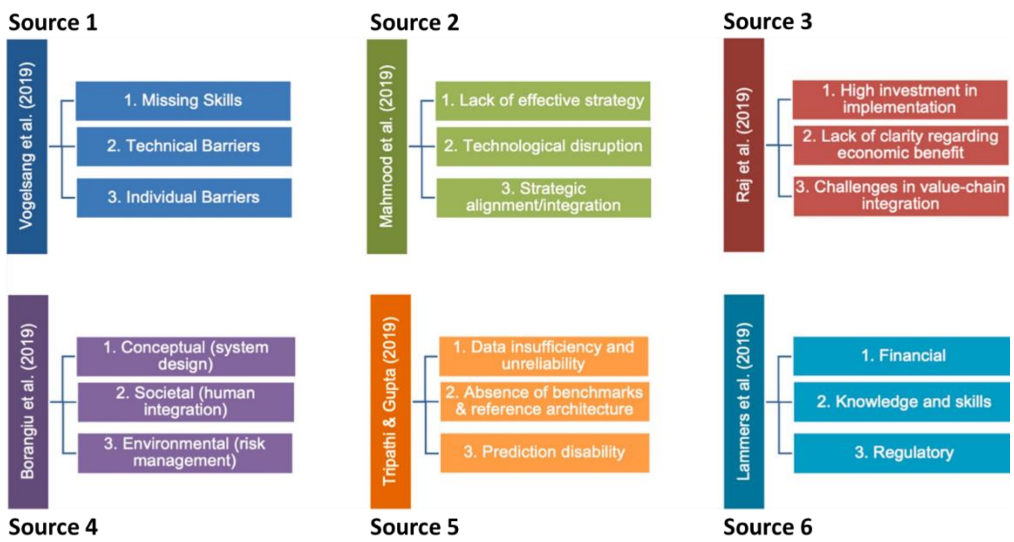


Figure 5.8: Top 3 barriers identified in recent publications (Jones, Hutcheson, & Camba, 2021))

To ensure that these top 3 barriers are addressed within the chosen Maturity Model, VDMA IMPULS Model, a mapping exercise was carried out (Table 5.13).

		Source 1	Source 2	Source 3	Source 4	Source 5	Source 6
Strategy and Organisation	Strategy	Individual barriers	Lack of effective Strategy Strategic Alignment/ integration	Lack of clarity regarding economic befits			
	Investments	Technical barriers		High investments in implementation			Financial
	Innovation Management		Technological disruptions				
Smart Factory	Digital modelling						
	Equipment infrastructure	Technical barriers					
	Data Usage						
	IT Systems						
SMART Operations	Cloud usage						
	IT Security						
	Autonomous Processing						

	Information Sharing			Challenges in value-chain integration			
SMART Products	ICT Add-on functionalities						
	Data Analytics Usage Phase					Prediction disability	
Data Driven Services	Data Driven Services					Data Insufficiency and unreliability	
	Share of revenues						
	Share of Data Used						
Employees	Employees Skill set	Missing Skills Individual Barriers					Knowledge and skills
	Skill Acquisition						
Not allocated					Conceptual System Design Societal (Human Integration) Environmental Risk Management	Absence of benchmarks and reference architecture	Regulatory

Table 5.13: Mapping Top 3 barriers against VDMA Model (Author)

Some barriers, for example, “Individual barriers” by Source 1, could be addressed within two dimensions “Strategy” and “Employees Skill set”. Lack of skills might become an individual barrier. There are five (5) barriers which are not aligned directly with any dimension.

Conceptual system design – this is addressed by developing the I4EM framework.

Societal (Human Integration) – This research work primarily focused on the integration of Industry 4.0 technologies; hence human integration is not a key concern.

Environmental risk management – Within the context of this work, the integration of Industry 4.0 technologies is not a prime concern.

Absence of benchmarks and reference architecture – Use of Industry 4.0 in emergency management is a relatively new area of research and no benchmarks or reference architectures were found.

Regulatory – If there is a case, regulatory issues may be addressed within the strategy dimension.

5.5.3 VDMA IMPULS Model as the base model

The main purposes of section 5.3 were to (a) identify the Implementation challenges of Industry 4.0 and Digital Transformation and (b) select a suitable Industry 4.0 maturity model for the emergency management sector. In section 5.3.1, three (3) leading maturity models were evaluated to identify the most suitable maturity model for the development of the I4EM framework. This evaluation concluded that VDMA IMPULS Model is the best-suited model. To ensure that all potential concerns are considered within the development of the new framework, the analysis was extended to include the barriers of digital transformation. Based on the key barriers identified in [Jones, Hutcheson, & Camba, 202137], a mapping exercise was carried out(Section 5.3.2) to assess whether those barriers are addressed by the VDMA IMPULS model. Out of a total of 18 Top three (3) barriers, it was possible to link thirteen (13) barriers to the dimensions of the VDMA IMPULS model. The remaining five (5) are not directly relevant to the development of the I4EM framework.

Therefore, it was decided to use VDMA IMPULS model as the basis of developing a maturity model for the proposed framework. To adopt this model for emergency management, some alterations are required.

5.6 Adapting VDMA IMPULS model to generate I4EM framework components

As discussed above VDMA IMPULS model was designed for the manufacturing industry, therefore, some adjustments are required to use in the emergency management sector. (Table 5.14) summarises the changes and provides the rationale for the changes.

Dimension	Sub-Dimensions	Change to
Strategy and Organisation (To what extent is Industry 4.0 established and implemented in your company's strategy?*)		
	• Strategy • Investments • Innovation Management	
Smart Factory (To what extent does your company have digitally integrated and automated production based on cyber-physical systems?*)		• This is a manufacturing-oriented dimension. Remove "Smart Factory" and move relevant sub-dimensions to "Smart Operations."
	• Digital Modelling • Equipment Infrastructure • Data Usage • IT Systems	• Remove "data usage" as it is to be covered under "data-driven services". • Merge "Equipment Infrastructure" with "Autonomous Process" to consider both processes and resources concurrently. • Move others to "Smart Operations"
Smart Operations (To what extent are the processes and products in your company digitally modeled and capable of being controlled through ICT systems and algorithms in a virtual world?*)		• Redefine "Smart Operations" (To what extent do stakeholders have been digitally integrated and automated services based on cyber-physical systems?)
	• Cloud Usage • IT Security • Autonomous Processes • Information Sharing	• Move "Information Sharing" to "Data-driven services"
Smart Products (To what extent can your products be controlled with IT, making it possible for		• Rename as "Smart Equipment" to reflect the use of devices such drones and autonomous robots.

them to communicate and interact with higher-level systems along the value chain?*)		
	• ICT add-on functionalities • Data analytics in usage phase	• Remove "ICT add-on functionalities" as it is specific manufacturing systems software. • Move "Data analytics in usage phase" to "Data Driven services "
Data-driven services (To what extent do you offer data-driven services that are possible only through the integration of products, production and customers?*)		• Redefine "Data-Driven Services" (To what extent do you offer data-driven services that are possible only through the integration of stakeholders and services?)
	• Data-driven services • Share of revenues • Share of data used	• Remove "share of revenues" as this is not relevant in emergency management scenarios.
Employees (Does your company possess the skills it needs to implement Industry 4.0 concepts?*)		
	• Employee skill sets • Skill acquisition	

Table 5.14: Adapting VDMA IMPULS models for I4EM Framework (Author)

(*) these definitions are from https://www.industrie40-readiness.de/?sid=62931&lang=en

The resulting model for I4EM framework is shown in (Table 5.15).

Dimension	Sub-Dimensions
Strategy and Organization (To what extent is Industry 4.0 established and implemented in your company's strategy?*)	• Strategy • Investments • Innovation Management
Smart Operations To what extent does stakeholders have been digitally integrated and automated services based on cyber-physical systems?)	• Cloud Usage • IT Security • Autonomous Processes • Digital Modelling • Equipment Infrastructure • IT Systems
Smart Equipment **(To what extent can your equipment be controlled with IT, making it possible for them to communicate and interact with higher-level systems along the value chain?)**	• Smart Devices
Data-driven Services (To what extent do you offer data-driven services that are possible only through the integration of stakeholders and services?)	• Data-driven services • Share of data used (includes data usage) • Data analytics in the usage phase • Information Sharing
Employees (Does your company possess the skills it needs to implement Industry 4.0 concepts? *)	• Employee skill sets • Skill acquisition

Table 5.15: Selected Dimensions and Sub-Dimensions

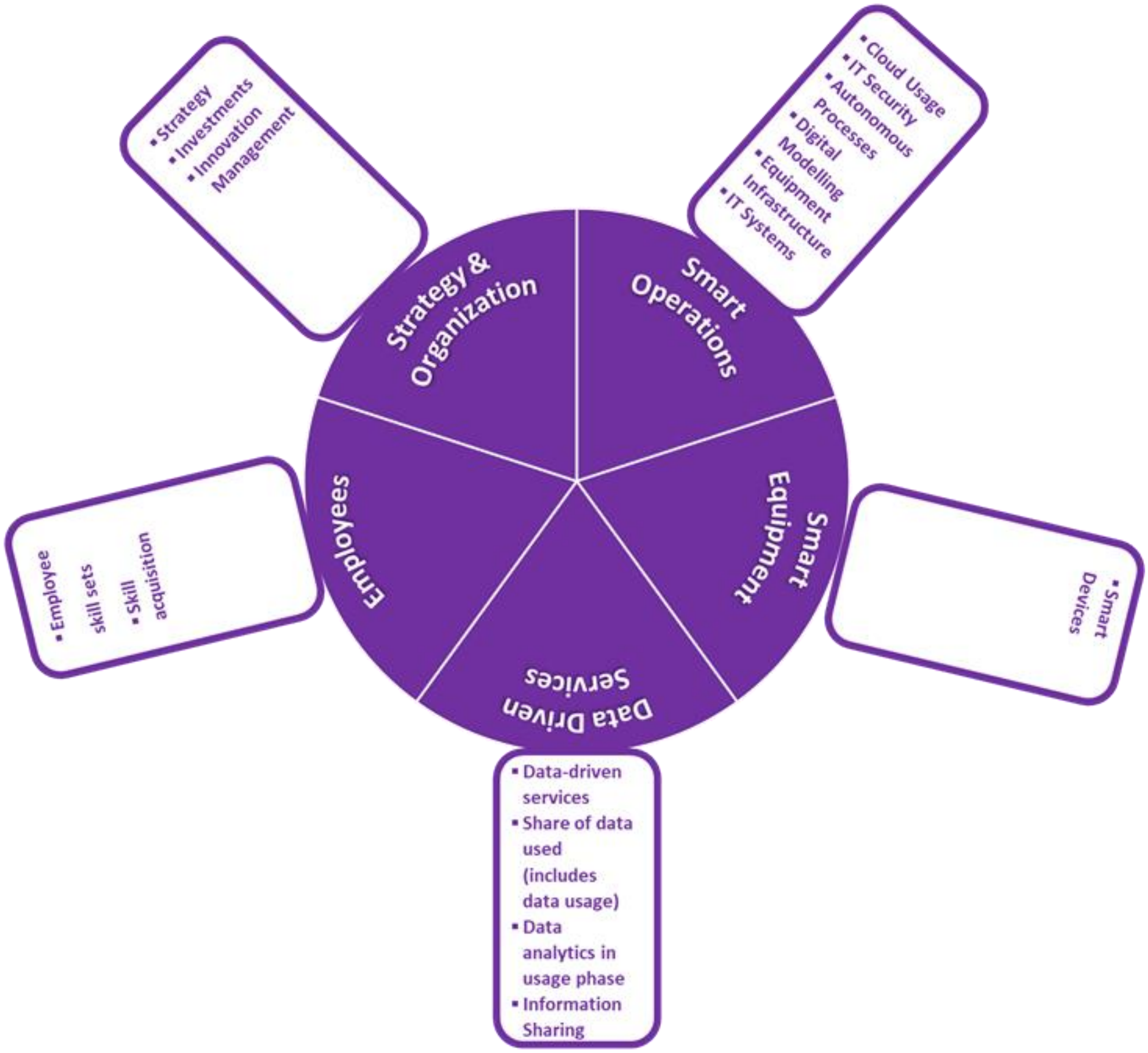


Figure 5.9: I4EM Readiness Model

The next step is to develop a maturity model which assists organisation to assess its current level of capabilities and develop strategies for continuous improvements.

5. 7 Maturity Model

Since the introduction of the concept of maturity models in 1993 (Paulk, 1993) for the software development process, maturity models have been developed for many subject areas for example Project Management (Combe ,1998) and Business Process Management (Röglinger et al. (2012)). The inception of Industry 4.0 also led to the development of maturity models (Basl, 2018). Maturity models assist organisations of current capabilities and then plan a journey for continuous improvement (Brookes et sl., 2014). In order to use the model developed in the section 5.4, it is necessary to have an associated maturity model. Maier et al. (2011) presents a methodology to design maturity models. A maturity grid typically consists of a group of "dimensions" and "different values" of these dimensions. Different values inform different levels of capabilities or readiness.

The number of levels varies from model to model. For example, WMG Industry 4.0 Readiness Model had 4 levels where as VDMA IMPULS Model has 6 levels. Within the context of this study, Level 0 (outsider) and Level 6 (Top Performer) of VDMA IMPULS Model are not relevant, as the framework is developed for the UAE National Response Framework. Therefore, for this study, four levels which are common to both WMG and VDMA were chosen.

- Level 1 Beginner
- Level 2 Intermediate
- Level 3 Experienced
- Level 4 Expert

Based on the information gathered from the existing maturity models and the knowledge gained from the literature analysis the following maturity model was created.

Dimension: **Strategy and Organisation**				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Strategy (to recognise Industry 4.0 as a key technology platform)	Industry 4.0 is recognised by individuals or by departments but not an integral element of the strategy	Industry 4.0 is included in the strategy, but stakeholders are not aware of the strategy	Industry 4.0 is included in the strategy and is widely communicated to stakeholders	Industry 4.0 is recognised as a core technology and senior executives take responsibility for leading the implementation
Investments (on Industry 4.0 technologies)	Limited investments in a specific area	Investments in a few areas but lacks a coherent approach	Investments in many areas but lacks a clear strategy	Clear investment strategy is in place, and it is clearly communicated

Innovation Management (to develop innovative applications of industry 4.0)	There is no culture of innovation management	Innovation is encouraged at department level	Innovation is encouraged at all levels but there is no clear strategy	Clear innovation strategy is in place, and it is actively encouraged at all levels

Table 5.16: Strategy and Organisation Dimension (Author)

Dimension: **Smart Operations**				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Cloud Usage (use of Cloud Computing)	Ad hoc use of Cloud Computing and limited awareness	Opportunistic use of Cloud Computing driven by the vendors	A systematic approach to using Cloud Computing is in place.	Cloud Computing is a strategic priority and is well understood by all stakeholders
IT Security	No coherent strategy and the use of traditional IT security methods	Strategy is based on traditional IT security methods	Mix use of traditional methods and blockchain technology	Blockchain as the primary cyber security approach
Autonomous Processes (Includes Equipment infrastructure)	Limited awareness of autonomous technologies and ad hoc use of autonomous processes and equipment in emergency management	Department level awareness with applications in their own areas	Awareness across stakeholders involved in emergency management but disparate applications	Strategy to embed autonomous technologies and ensures connected systems and applications
Digital Modelling	Use of digital modelling for the prepare phase (training)	Use of digital modelling for prepare (training) and recovery (optimising) phases	Digital modelling as a core competency across all phases of emergency management	Digital modelling as a strategic tool and embodiment of digital-twins concept
IT Systems	Bespoke IT systems for local processes with little or no integration	Islands of automated systems	Corporate level IT systems integrated with essential bespoke systems	Cloud enabled fully integrated systems with Edge Computing capabilities for fast responses

Table 5.17: Smart Operation Dimensions (Author)

Dimension: **Smart Equipment**				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Smart Devices (Use of smart devices)	Smart devices are used but are not connected with other systems	Smart devices are used and partly connected with other systems.	Smart devices are used and fully integrated with other systems, but the integration limited to exchange of information	Smart devices are used and integrated with other systems and the integration ensures the optimal use of the devices.

Table 5.18: Smart Equipment (Author)

Dimension: **Data Driven Services**				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Data-driven services	Data is collected but not used to improve services in phased emergency management	Ad hoc use of data to improve services	Data is identified as a strategic asset and used to improve services	Data-driver services is a strategic priority
Data analytics in usage phase	Descriptive analysis to provide insights into past emergencies	Descriptive and diagnostics analysis of past emergencies	Predictive analytics in mitigate and prepare phases	Predictive analytics as a strategic tool in emergency management
Information Sharing	Information sharing in a few selected areas	Information sharing with trusted stakeholders and partners	Information sharing with all stakeholders and partners but limited to non-sensitive information	Information sharing involving both sensitive and non-sensitive data using cloud and blockchain technologies

Table 5.19: Data Driven Services Dimensions (Author)

Dimension: **Employees**				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Employee skill sets	Little understanding of digital technologies	Digital technology skills in technology focused areas	Digital technology and analytics skills across all areas	Deep knowledge on digital technologies and analytics
Skill acquisition	Self-learning on Industry 4.0 technologies	Organised events in local areas on Industry 4.0 technologies	Corporate level training for Industry 4.0	Strategy to develop Industry 4.0 technology competencies in all relevant areas

Table 5.20: Employee Dimensions (Author)

The above tables are represented by the building block, I4EM Maturity Model below (Figure 5.10)

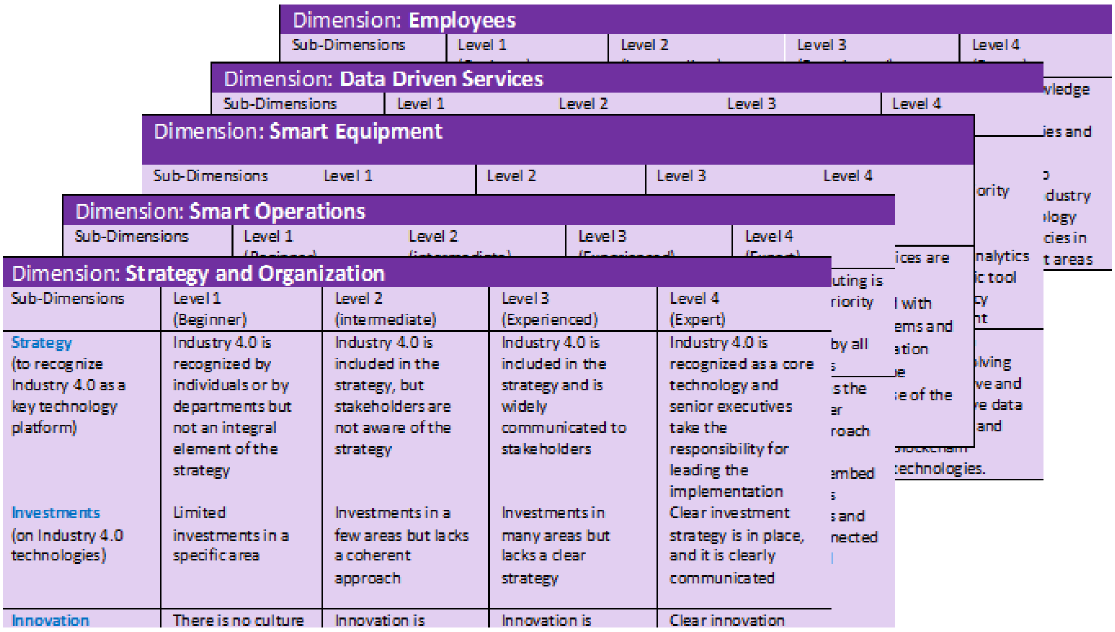


Figure 5.10 : I4EM Maturity Model (Author)

5.8 Developing Key Performance Indicators in Emergency Management

One of the famous quotes from Peter Drucker (Drucker, 1995), a well-known and influential thinker on management, is "you can't manage what you can't measure." This means Key Performance

Indicators are essential in any type of organization. Without them, it is not possible to make a rational judgment on the impact of changes.

The deployment of Industry 4.0 technologies in emergency management should improve the overall efficiency and effectiveness of every phase of the emergency management cycle. Therefore, it is absolutely necessary to have a KPI framework in place for emergency management. However, very little information is available on the published literature. Patrisina et al. (2018) present a set of Key performance indicators for disaster preparedness of "individuals" using a tsunami disaster as a case study but not about the performance of emergency management phases. The focus is on "individuals" rather than "systems". Huggins et al. (2015) present a set of KPIs that can be used to measure "community resilience work" focusing on the preparedness phase. Zagorecki et al. (2012) discuss the development of "Executive Dashboards" for emergency management. Whilst the authors stress the importance of using Executive Dashboards, they argue that identifying appropriate KPIs is challenging as multiple organisations are involved emergency management and different KPIs maybe required for different types of emergencies. A doctoral research programme by Ludík (2015), developed a process framework for emergency management in the Czech Republic. This work refers to use of KPIs in the development of a framework but no specific KPIs are identified. Moore (2016) discussed the development of KPIs for the preparedness of emergency management in hospitals. Few other works focus on the development KPIs humanitarian supply chains, which are critical for a speedy recovery from disasters (Masood et al., 2017) and (Toklu,2017).

Although this research primarily focuses on the use of Industry 4.0 technologies in emergency management, it is important to include the development of KPI system to measure the impact of Industry 4.0. At present there are no generic frameworks to measure the impact of Industry 4.0. A few studies have focused on specific aspects.

- Žižek, et al. (2020) – Key Performance Indicators and Industry 4.0 – *A Socially Responsible Perspective*
- Felsberger et al. (2020) - The impact of Industry 4.0 on the *reconciliation of dynamic capabilities*: Evidence from the European manufacturing industries
- Torbacki & Kijewska (2019). Identifying Key Performance Indicators to be used in Logistics 4.0 and Industry 4.0 for the needs of *sustainable municipal logistics* by means of the DEMATEL method. Transportation Research Procedia, 39, 534-543.

A model developed by Sader et al. (2017) to measure the impact of Industry 4.0 on Total Quality Management present a more generic KPI framework which can be adapted to measure the impact of Industry 4.0 on emergency management.

TQM Principles	**Indicators for improvements (TQM)**	**Industry 4.0 impact (TQM)**
Customer Focus	Customer satisfaction and loyalty Growth % in customers' base , Improved organisation's reputation	Response time to customers' orders, product customisation and new product developments Easy to gather customer feedback through smart product connectivity Realtime in-field performance product monitoring
Leadership	Unity of purpose among the organisation Aligned strategies, policies, processes and resources Effective communication between all administrative levels	Effective allocation of different resources (operational effectiveness) Increased revenues due to optimised allocation of resources
Engagement of people	Increased motivation of people Increasing innovative ideas Enhanced people satisfaction Self-evaluation and self-improvement culture	Number of innovative ideas or initiatives created or taken by employees Increased value (%) of employees' satisfaction Increased revenues due to less human related failures Number of problems solved by employees
Process approach	Identify key processes and points of improvements Optimised performance and effective process management	Number of process re-design activities made because of data analysis and enhancement decisions Production lead time Suppliers' responsiveness to new supply orders

	Manage processes and interrelations, as well as dependencies	In-process real-time quality control activities (percentage of defects) Decreased percentage of processing downtime •
Improvements	Responsive systems to customer requirements Enhanced ability to react to the development of processes, products and market needs Support drivers for innovation	Enhanced percentage of response time (production lead time) The range of customisation options that can be business without affecting the normal productivity rates Number of newly developed products and time needed to introduce it to markets
Evidence-based decision making	Clear and agreed on decision-making process Data availability and clarity Effective past decisions, Analyse and evaluate data using suitable methods and tools.	Increased revenues due to recently take decisions Number of reporting and automatic recommendations learned by or from the smart production system Ease of data mining and friendly presentation of results and recommendations
Relationship management	Stakeholders are identified and suitable communication tools to each are known Stakeholders are satisfied, and their feedback is considered, Suppliers are responding to materials requests on time and at the required quality, Supply chain is stable and no downtime due to lack supply	Number of received to processes communications from stakeholders The rate of satisfaction for stakeholders is improving continuously Improved suppliers' responsiveness rate Percentage of downtime due to lack of supply is in its minimum value

Table 5.21: KPIs in TQM Implémentations (Sader et al. (2017))

Using the above (Table 5.20) table as the bases, the following reference model was developed to measure the impact of Industry 4.0 technologies in emergency management.

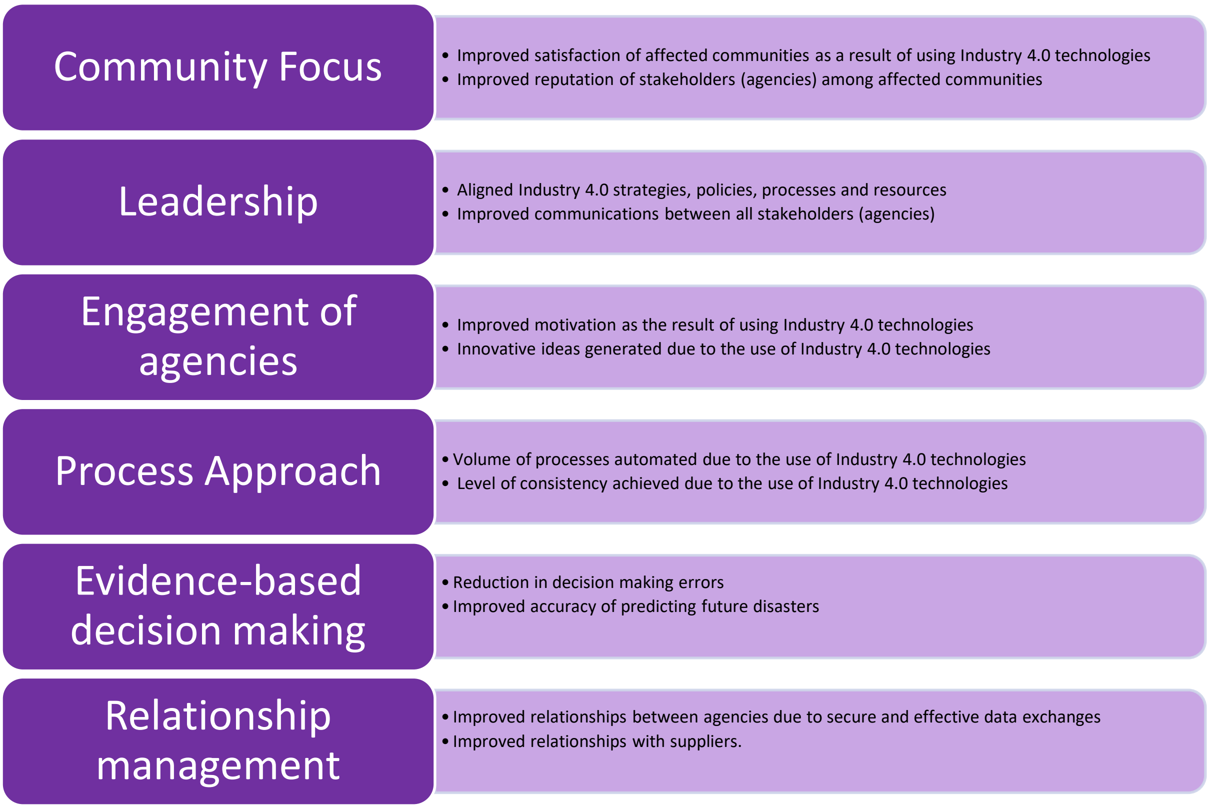


Figure 5.11: Improvements to I4EM KPI Reference Model

5.9 Digital Twins in Emergency Management

One of the important outcomes of deploying Industry 4.0 is the creation of digital twins (El Saddik (2018), Stark et al. (2019)). Using Industry 4.0 technologies, it is possible to create “a live replica” (twin) of a real system. Then digital twins can be used to study the behaviour of the real system and control the real systems. Although the development of digital twins is a relatively new concept, with a limited number of real-world examples, it is expected to become one of the important digital tools in the future. Research work has already commenced studying the use of digital twins in emergency management. Mohammadi & Taylor (2021) outline how digital twins can be used to improve decision making in emergency management (Figure 5.12). Elements of the models (denoted by a,b,c, and d) are as follows:

(a) Fast-onset (for example, earthquake, tornado, tsunami) and slow-onset (flooding, drought) disaster events result in change processes in real cities that vary in terms of the pace and duration of change.

(b) Heterogeneous data needs to be captured at a mixed frequency and integrated into Smart City Digital Twin models in real-time at the corresponding frequencies that change processes are taking place.

(c) A digital twin informs decision-makers who must use a combination of fast and slow thinking to adaptively devise interventions at various levels of urgency.

(d) Decision-makers generate time-critical decisions that impact the real environment, and the cycle continues as new interventions — and ultimately new policies/strategies — generate new change processes in the real world.

In this conceptual paper, the author argues that further work is required to capture city dynamics accurately in digital twins.

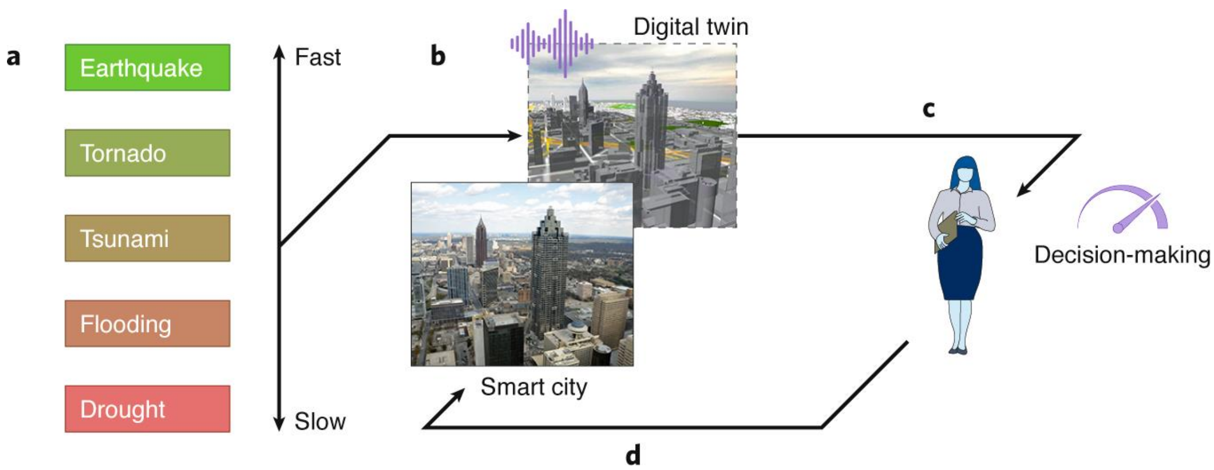


Figure 5.12: Conceptual Model for Digital Twins within the context of emergency management (Mohammadi, & Taylor, 2021)

Fan et al. (2021) present a vision for a Disaster City Digital Twin paradigm that can provide increased visibility into network dynamics of complex disaster management and humanitarian actions (Figure 5.13). Their proposed paradigm includes four complimentary (4) technologies:

- multi-data sensing for data collection

- data integration and analytics
- multi-actor game-theoretic decision making
- dynamic network analysis

They argue that the convergence of the above technologies creates a strong promise for enhancing the performance of disaster management processes.

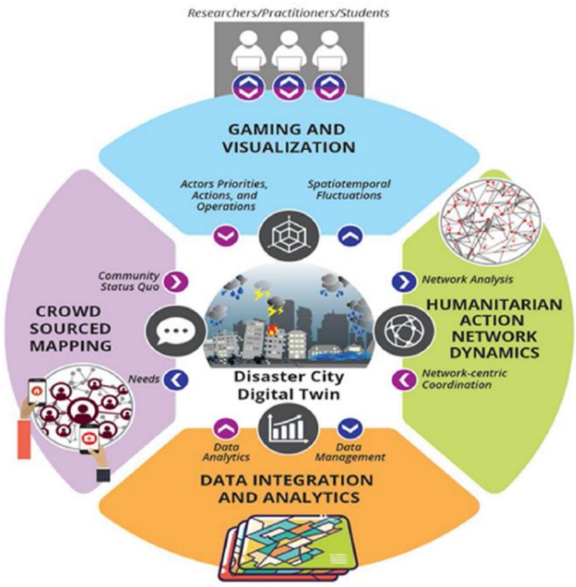


Figure 5.13: Disaster City Digital Twin paradigm (Fan et al. 2021)

Ford & Wolf (2019) also presents a conceptual framework for developing digital twins for emergency management (Figure 5.14).

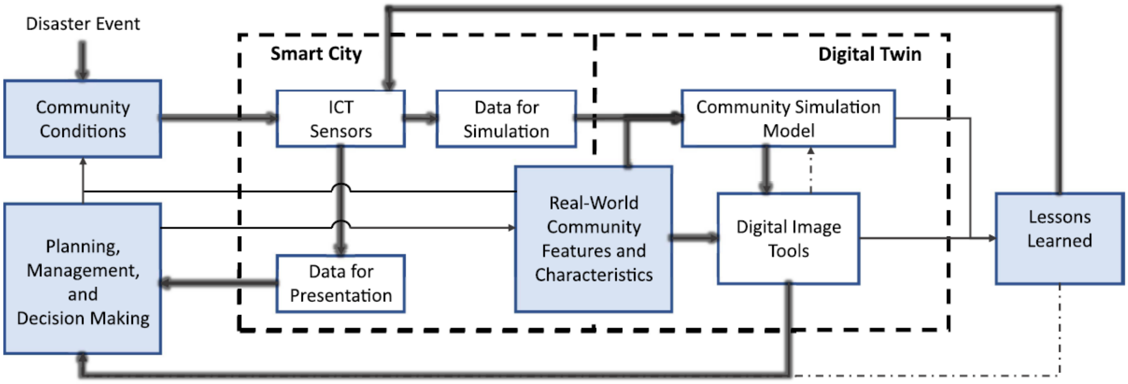


Figure 5.14: Conceptual framework for developing digital twins (Ford & Wolf, 2019)

These authors also argue that further research and developments are required to make the use of digital twins in disaster management a reality.

Although the use of digital twins for emergency management may be years away, the researcher strongly believes that it should be an integral element of the I4EM framework. As the UAE National Emergency Framework reaches higher levels of Industry 4.0 maturity, it should pave the way to develop digital twins for emergency management.

A review of the literature identified two proposed frameworks for building digital twins of smart cities.

Framework 1: DUET: T-Cell framework for creating digital twins (Raes et al. 2021)

This work has produced a T-cell framework to create digital twins (Figure 5.15). It includes a repository of models and an interface to gather live data. This framework is being tested in three cities in Europe.

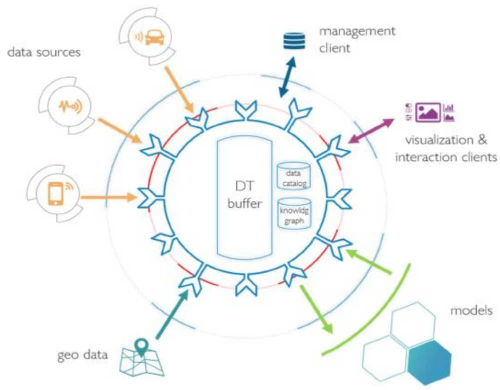


Figure 5.15: T-Cell framework for creating digital twins (Raes et al. 2021)

Framework 2: A generic framework for building digital twins of cities (Deng et al. 2021)

Following a systematic review of literature, the authors have created a generic model which identifies three main elements (a) infrastructure to collect and exchange data; (b) urban brain which includes models and data platforms and c) applications which include disasters and emergencies.

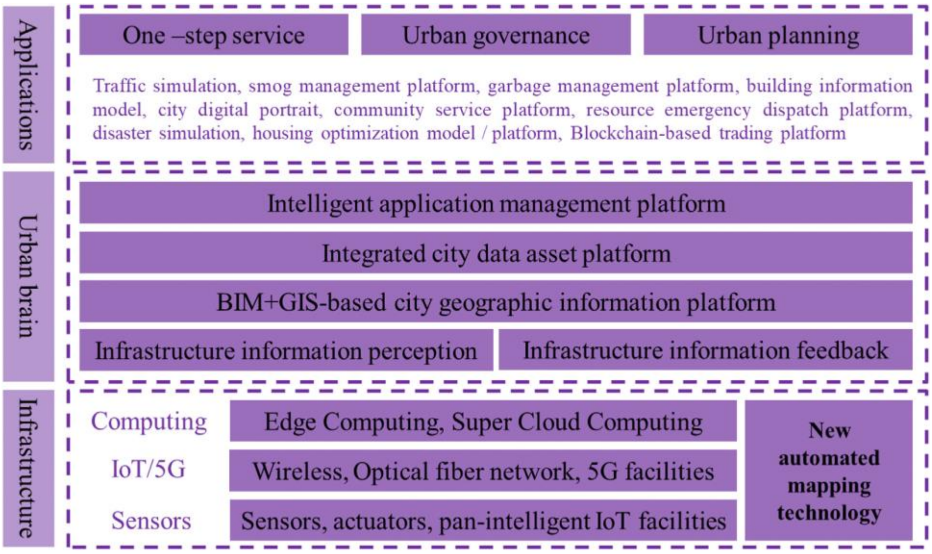


Figure 5.16: A generic framework for building digital twins of cities (Deng et al. 2021)

As this model clearly outlines the key building block of developing digital twins, It is suggested that this model is used as reference model for developing digital twins for emergency management i.e. I4EM Digital Twin Reference Model.

5.10 Creating a model for Knowledge Management

As reported in the literature review (section 2.9), none of the existing emergency management models highlight the importance of "knowledge management" explicitly. Knowledge gathered from emergency management episodes are critically valuable in the continuous improvement of emergency management cycles.

Knowledge management refers to the creation, distribution and utilisation of knowledge for strategic advantage (North & Kumta (2018)). Disasters and emergency management episodes generate a vasts amount of data and experiences. However, Kaklauskas, et al. (2009) argue these valuable experiences are not captured, managed and shared among partners effectively to improve emergency management in a sustainable manner. Moe et al. (2007) argues that disaster management practitioners must learn from real experiences to enhance their knowledge and skills continually.

Oktari et al. (2020) who have conducted an exhaustive systematic literature review involving 72 publications on the knowledge management practices in disaster management, conclude that:

(a) the number of publications on the subject has been steadily increasing. However, most publications are on knowledge management in flood-related disasters.

(b) None of the applications include knowledge relating to all three dimensions, people, process and technology.

(c) Effective knowledge management can reduce the impact of disasters, but further research is required to develop a holistic knowledge management system.

Although the development of a knowledge management system is outside of the scope of this work, the following conceptual model (Figure 5.17) is proposed as the basis for developing a knowledge management system. The foundation of the knowledge is generated from Critical Success Factors (CSF) and Critical Failure Factors (CFF) collated from the agencies involved in disasters.

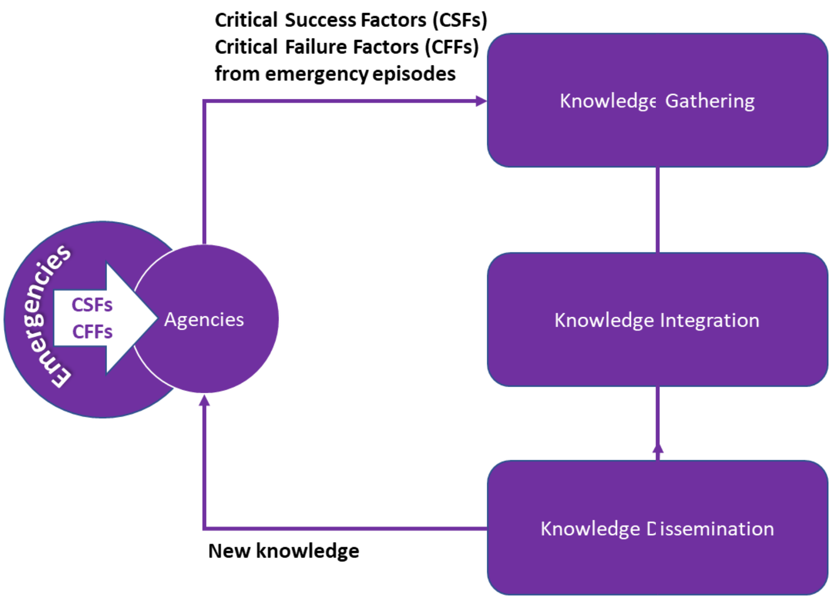


Figure 5.17: I4EM Knowledge Management Reference Model

5.11 I4EM Framework

The above sections presented the development of building blocks for the I4EM framework. This section illustrates the assembly of those building blocks to create the I4EM framework.

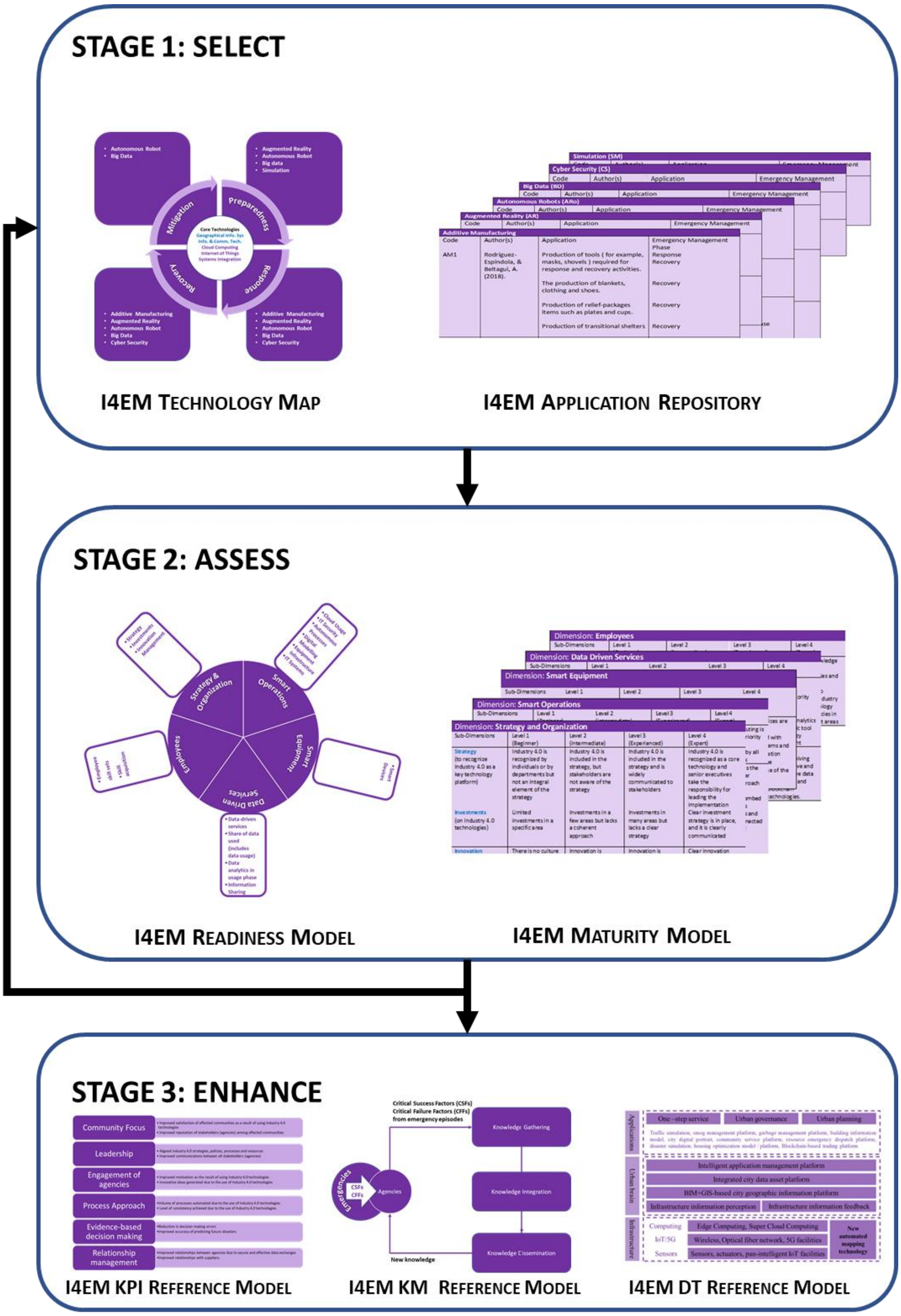


Figure 5.18: I4EM Framework (Author)

STAGE 1: SELECT

The main purpose of this stage is to identify one or more Industry 4.0 technologies for implementation. The current Technology Map shows the emergency management phases where technologies are currently being used. Then I4EM Technology Map and I4EM Application repository can be used to identify one or more Industry 4.0 technologies that can be used to enhance the UAE Emergency Management Framework.

STAGE 2: ASSESS

Having identified a potential technology for implementation, the main purpose of this stage is to assess the readiness of the organisation for implementing the chosen technology. Radar Diagrams are typically used to visualise the current level of readiness.

For example, Smart Operations Dimension of the I4EM Readiness Model has five (5) sub-dimensions. Stakeholders can collectively decide the current level of maturity for each dimension. Table 5.22 shows an example of maturity levels for Smart Operations. The current level of readiness is highlighted.

Dimension				
Sub-Dimensions	Level 1 (Beginner)	Level 2 (intermediate)	Level 3 (Experienced)	Level 4 (Expert)
Cloud Usage (use of Cloud Computing)	Ad hoc use of Cloud Computing and limited awareness	Opportunistic use of Cloud Computing driven by the vendors	A systematic approach to using Cloud Computing is in place.	Cloud Computing is a strategic priority and is well understood by all stakeholders
IT Security	No coherent strategy and the use of traditional IT security methods	Strategy is based on traditional IT security methods	Mix use of traditional methods and blockchain technology	Blockchain as the primary cyber security approach
Autonomous Processes (Includes Equipment infrastructure)	Limited awareness of autonomous technologies and ad hoc use of autonomous processes and equipment in emergency management	Department level awareness with applications in their own areas	Awareness across stakeholders involved in emergency management but disparate applications	Strategy to embed autonomous technologies and ensures connected systems and applications
Digital Modelling	Use of digital modelling for the prepare phase (training)	Use of digital modelling for prepare (training) and recovery (optimising) phases	Digital modelling as a core competency across all phases of emergency management	Digital modelling as a strategic tool and embodiment of digital-twins concept

IT Systems	Bespoke IT systems for local processes with little or no integration	Islands of automated systems	Corporate level IT systems integrated with essential bespoke systems	Cloud enabled fully integrated systems with Edge Computing capabilities for fast responses

Table 5.22: An example of the current level of maturity (Smart Operations)

Once the current level of maturity is established, Radar diagram can be used to visualise the findings.

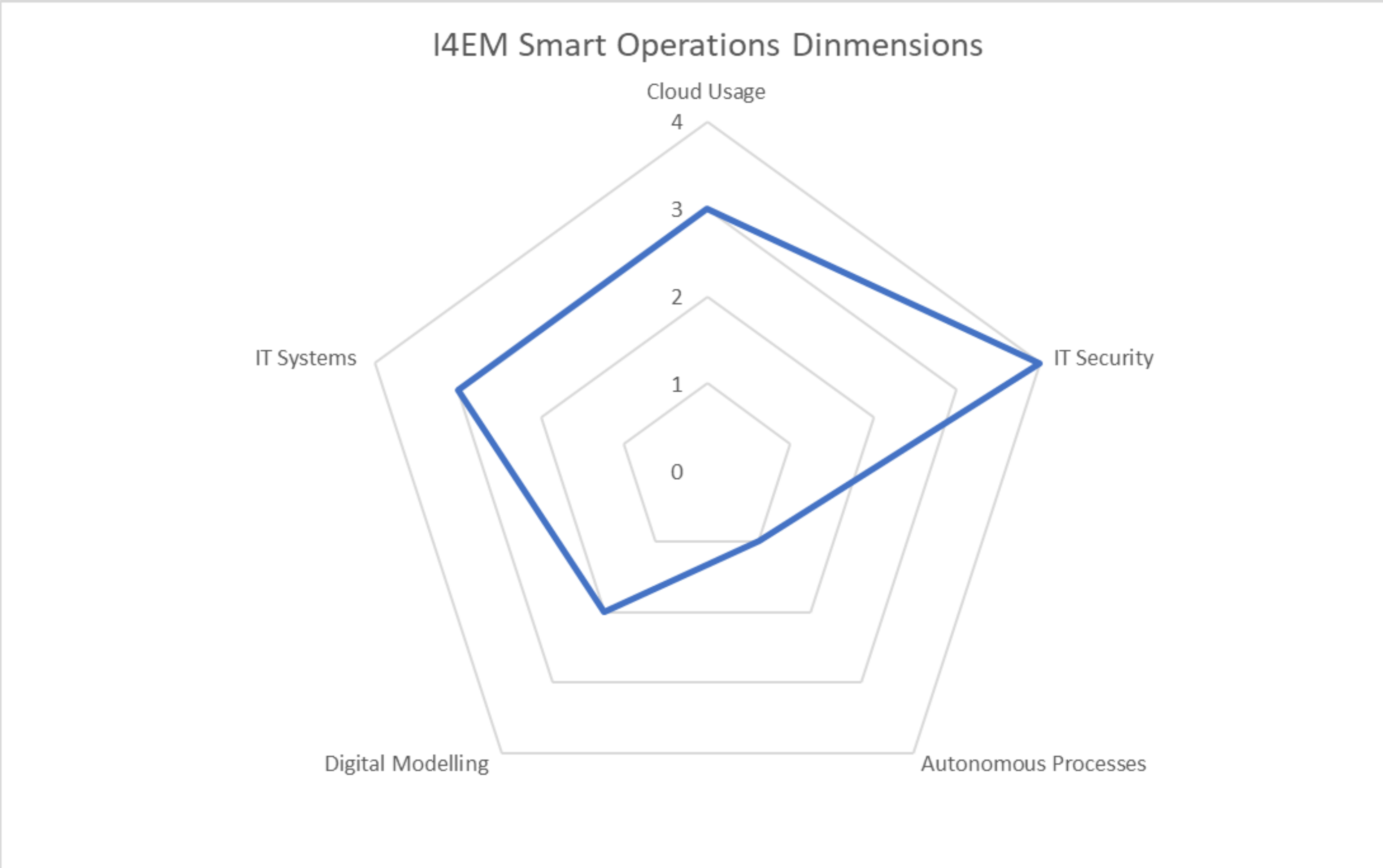


Figure 5.19 : An example of Radar Diagram (Author)

STAGE 3: Enhance

Implementation of new technologies are expected to deliver improved performance and may open up opportunities for further enhancements. Once the core Industry 4.0 technologies (Cloud Computing, Systems Integration) are in place, it should be possible to gather more operational data from emergencies. These data then can be utilized to support continuous improvements, hence the three reference models. The purpose of these three reference models is to emphasise the fact that these three areas, Key Performance Indicators (KPIs), Knowledge Management and Digital Twins, should be considered concurrently when Industry 4.0 technologies are added to the emergency management cycle.

5.12 Summary

The main purpose of this chapter is to present the systematic and methodological development of the I4EM framework. The process of development commenced with a summary of key observations made from the literature review, interviews, and the questionnaire survey. These observations were then used to create the design principles for the framework in which the identification key building blocks was considered as one of the prime tasks. Given that no previous attempt had been made to map the industry 4.0 technologies into the emergency management cycle, a comprehensive literature analysis was conducted to identify potential applications of each Industry 4.0 technology within the context of emergency management. This led to developing the *I4EM Application Repository* and the *I4EM Technology Map,* which provides a comprehensive catalogue of Industry 4.0 applications in emergency management. The framework building process then progressed to the development of *I4EM Readiness Model* and *IM Maturity model.* The key challenge of this step was identifying the most appropriate existing Industry 4.0 Readiness model. The logic behind this approach was not to “reinvent the wheel”. Instead developing models “from scratch “, it was decided to review existing readiness models and to reconfigure the best model to accommodate I4EM design needs. Through a ranking exercise, three (3) leading reediness models were chosen for exhaustive scrutiny and eventually, VDMA IMPULS Model was chosen as the best fit due to the generality of some of its dimensions. VDMA IMPULS Model was then gradually reconfigured to create I4EM Readiness Model. By taking each dimension of the newly created I4EM Readiness into consideration, I4EM Maturity Model was created by defining maturity levels for each dimension.

Four (4) building blocks developed from the above process were then assembled to create the draft i4EM framework. The next chapter outlines the validation of the framework and the final adjustments made to the framework.

Chapter 6 – Validation and Enhancement of the framework

6.1 Introduction

Although the development of the I4EM framework followed a systematic research approach, it is vital to assess the validity of the framework to ensure that the framework and its components are robust and applicable to the UAE emergency management community. This chapter presents the validation process deployed, feedback received, and amendments made to the framework.

6.2 Validation Techniques

Inglis (2008) presents a list of validation techniques that can be used in qualitative research projects. (Table 6.1)provides a brief description of each technique and a commentary on the suitability within the context of this research work.

Method	Description	Suitability
Gathering supporting evidence via a literature review.	Use the evidence in the literature for the validation	This research has already used a wide range of published literature to formulate the framework. Therefore, they cannot be used again to validate the framework. Given that this is the first known attempt to develop a framework in this area, there is no literature available on similar frameworks.
Seeking input from an expert panel	This brings in a higher level of expertise to the validation process. However, it is important to use more than one expert to reduce any bias in induvial responses. A clear brief is important to ensure the panel develop a good understanding of the topic under consideration.	Given that this framework is primarily designed for the UAE emergency management community, this is a very useful approach.
Undertaking survey research	Use of questionnaire surveys to access the validity.	This approach can be used in conjunction with gathering inputs from experts.

Conducting pilot projects	Designing and implementing a pilot project	The implementation of the framework cannot be realised in a short span. Hence this approach cannot be used in this work.
Drawing on case studies	Using the evidence from case studies in validation.	There are no case studies available for the implementation of Industry 4.0 framework in emergency management. Case studies relating to the use of individual Industry 4.0 technologies have been used in the formulation of the framework.

Table 6.1: Validation Techniques (Inglis .2008)

6.3 Validation strategy

Based on the above analysis, it was decided to use inputs from UAE emergency management experts supplemented with a questionnaire survey. With the view to ensure that the validation process is robust and methodological, the following steps were implemented.

Step 1: Identification a panel of experts

Eight (8) experts were drawn from the UAE emergency management community, mainly from the NCEMA and the Dubai Police. Due to ongoing Covid restrictions and increased operational duties due to Dubai Expo 2020, it was not possible to assemble a panel; hence individual meetings were arranged.

Step 2: Preparation of the brief

A brief comprising (a) the framework diagram and (b) a brief but a rich explanation of each building block and the rationale behind them, were produced. This was shared with the experts in advance of the meeting.

Step 3: Preparation of the survey the questionnaire

A questionnaire was produced to capture the viewpoints of the experts on (a) completeness of the framework (b) usefulness of building blocks and (c) clarity of the process. A space was also provided capture any general remarks. A copy of the questionnaire is provided in the Appendix 2.

Step 4: Meeting the expert

Given the topics of Industry 4.0 is relatively new among the UAE emergency management community, the main purpose the meeting was to ensure that they have a good undertaking of the framework prior to the responding to the questionnaire.

Step 5: Gathering responses to the questionnaire survey

The participants were given additional time after the meeting to complete the questionnaire. This enabled them to discuss their view with colleagues where it was necessary.

6.4 Results from the questionnaire survey

The results from the questionnaire survey is shown in the (Figure 6.1).

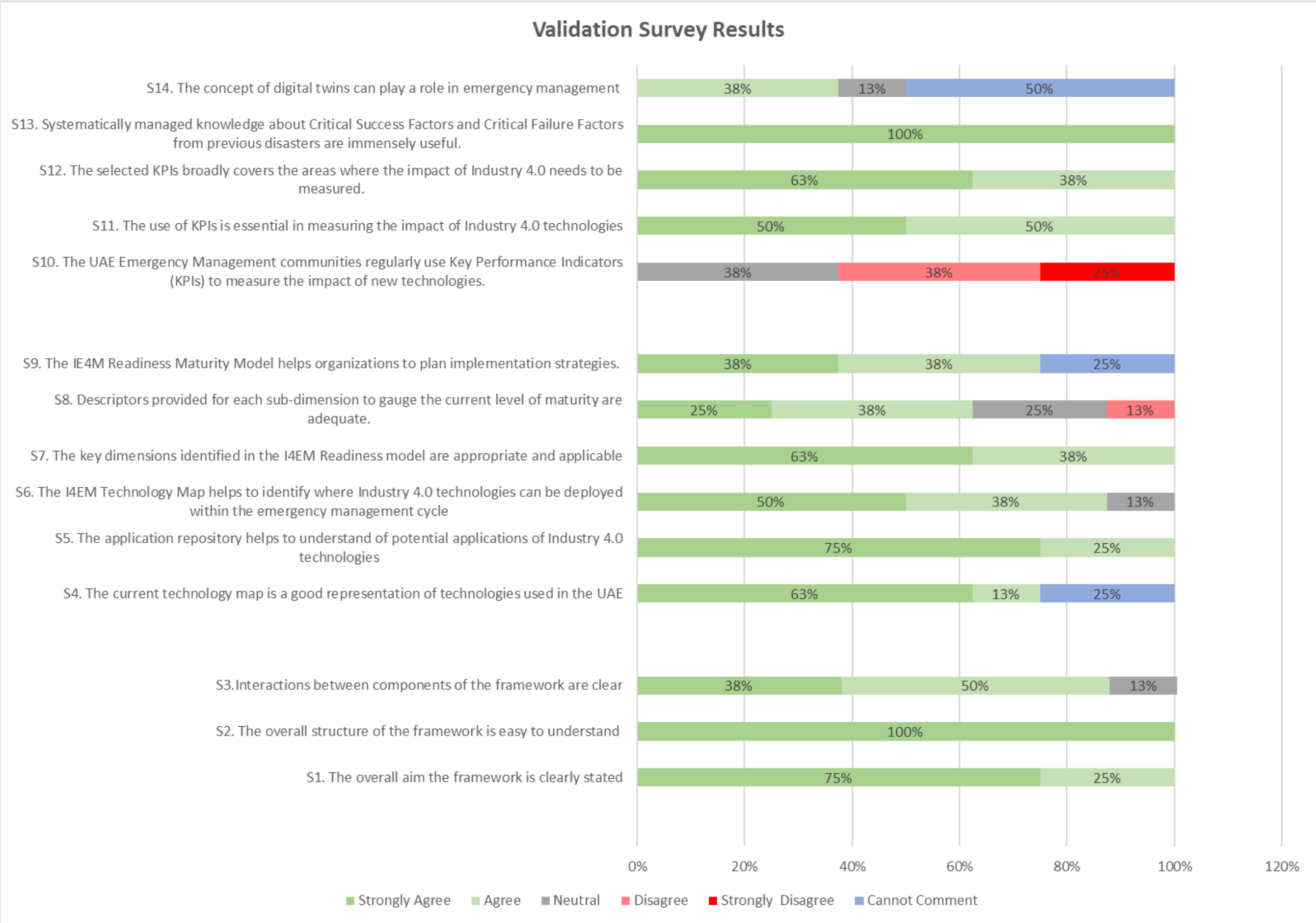


Figure 6.1: Results from the questionnaire Survey (author)

As seen in Figure 6.1, the participants broadly agree with the statements. However, there are a few exceptions.

S3.Interactions between components of the framework are clear

Whilst 88% of participants agree that the interactions between components are clear, the rest does not agree or disagree. Therefore, there is room for improvement on how interactions are explained in the framework.

S4. The current technology map is a good representation of technologies used in the UAE

A near 100% endorsement was expected for this technology map as it was built using information gathered from the interviews and the questionnaire survey reported in Chapter 4. But only 63% of participants strongly agreed with the statement. Interviews and the survey were conducted in 2018, since then some new technologies may have been added. The current technology map is a "live" map; this needs to be clarified in the model.

S8. Descriptors provided for each sub-dimension to gauge the current level of maturity are adequate.

It is acknowledged that further information on the sub-dimension is useful, but it is difficult to add further information to the tables. Typically, the maturity levels are determined by answering to detailed questions on the sub-dimensions. Therefore, it is possible to add further information when relevant questions are formulated. The statements in the tables (I4EM Readiness Maturity Models) aim provide the foundation for detailed statements/questions.

S9. The I4EM Readiness Maturity Model helps organizations to plan implementation strategies.

It is acknowledged that the information on the readiness model alone is not sufficient to develop implementation strategies. Information such as the overall strategies of the organization and investment plans are required to produce detailed implementation strategies. Established project management paradigms need to be used when implementation strategies are formulated and actioned.

S10. The UAE Emergency Management communities regularly use Key Performance Indicators (KPIs) to measure the impact of new technologies.

It appears that KPIs are not in regular use to assess the impact of using new technologies. This is a serious shortcoming. KPIs are an absolute necessity to assess the impact of introducing new technologies. Therefore, KPI model should be an integral part of the framework.

S14. The concept of digital twins can play a role in emergency management

Given that digital twins is an advanced and recent concept, the level of awareness is generally low. This was reflected in the responses. As explained in Chapter 5, digital twins can play a major role in emergency management, and the use of Industry 4.0 technologies can make it a reality.

Based on the above analysis, three (3) improvements needs to be implemented

- Further details on the interactions between components (S3)
- Clarification on the status of the current technology map (S4)
- Use of project management paradigms in the implementation phase (S9)

6.5 Summary of general comments

The final part of the questionnaire provided an opportunity to make general comments on the framework. Table 6.2 presents those comments and improvements to the framework where it is necessary.

Comment	Proposed improvement/Feedback
"Your work is interesting. I like to know more about Industry 4.0 techniques. Please share your final report with me."	N/A
"I think learning from other people's experiences is important. We miss it in here. I personally welcome the development of database".	It is good to note that the inclusion of knowledge management has been welcome.
"This is good, but I would like to see more information on how this can be implemented"	Additional information to be provided on the implementation of the framework.

"I hear UAE government is going to make an announcement about the industry 4.0 so your work might be useful".	This survey was conducted between April and May 2021. In October 2021, the UAE government launched a new strategy that aims to make the UAE a leading global hub for Industry 4.0,
"*This is good; I don't think our staff know anything about Industry 4.0*"	This is a fair comment. Currently, Industry 4.0 is not widely known in emergency management communities. Raising awareness of Industry 4.0 technologies is important and it should be part of the implementation plan.

Table 6.2: Comments from the participants (Author)

6.6 Enhancing the framework – Proposed Road Map for Implementation

The I4EM framework provides tools and core steps required to integrate Industry 4.0 technologies in emergency management. Given that Industry 4.0 is not widely known by the UAE emergency management communities, extra steps are required to ensure a sustainable implementation.

As expected, implementation roadmaps by other researchers focus on the manufacturing sector. Butt (2020) presents a strategic roadmap based on lean six sigma approaches. This roadmap consists of two stages, six sigma approach for the development of a new process chain and then continuous improvement plan. Based on a systematic literature review, Ghobakhloo (2018) proposes a strategic road map "towards" Industry 4.0. It identifies six strategic areas: (a) strategic management (b) marketing strategy (c) Human Resource Strategy (d) IT Maturity Strategy (e) Smart Manufacturing Strategy, and (f) Smart supply chain management strategy as pre-requites for the transitions to Industry 4.0. Each strategy includes several steps which eventually ensure the implementation of Industry 4.0 technologies. The implementation model proposed by Pessl, Sorko & Mayer (2017), have six phases. One of the key differences in this model is that the first phase focuses on "Raising Awareness" through structured workshops. This is critical in the case of emergency management.

Having analyzed the implementation patterns of 93 companies, Frank, Dalenogare & Ayala (2019) has produced a comprehensive and easy to understand implementation roadmap (Figure 6.2)

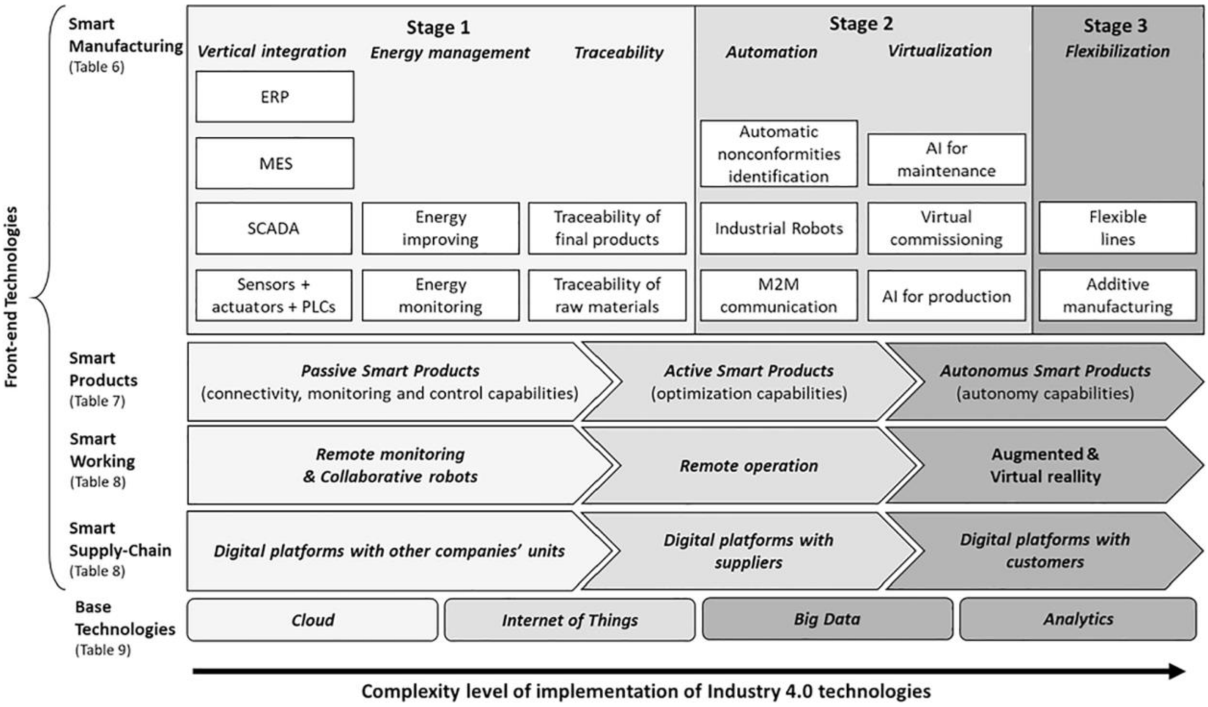


Figure 6.2: Framework summarizing the findings of the adoption patterns of Industry 4.0.(Frank, Dalenogare, & Ayala, 2019).

The distinctive feature of this model is that it refers to a set of base technologies on which other technologies are built-on. The I4EM Technology Map also identifies a set of core technologies that needs to be in place.

By combining a selection of elements from the existing model, the following implementation models is proposed (Figure 6.3)

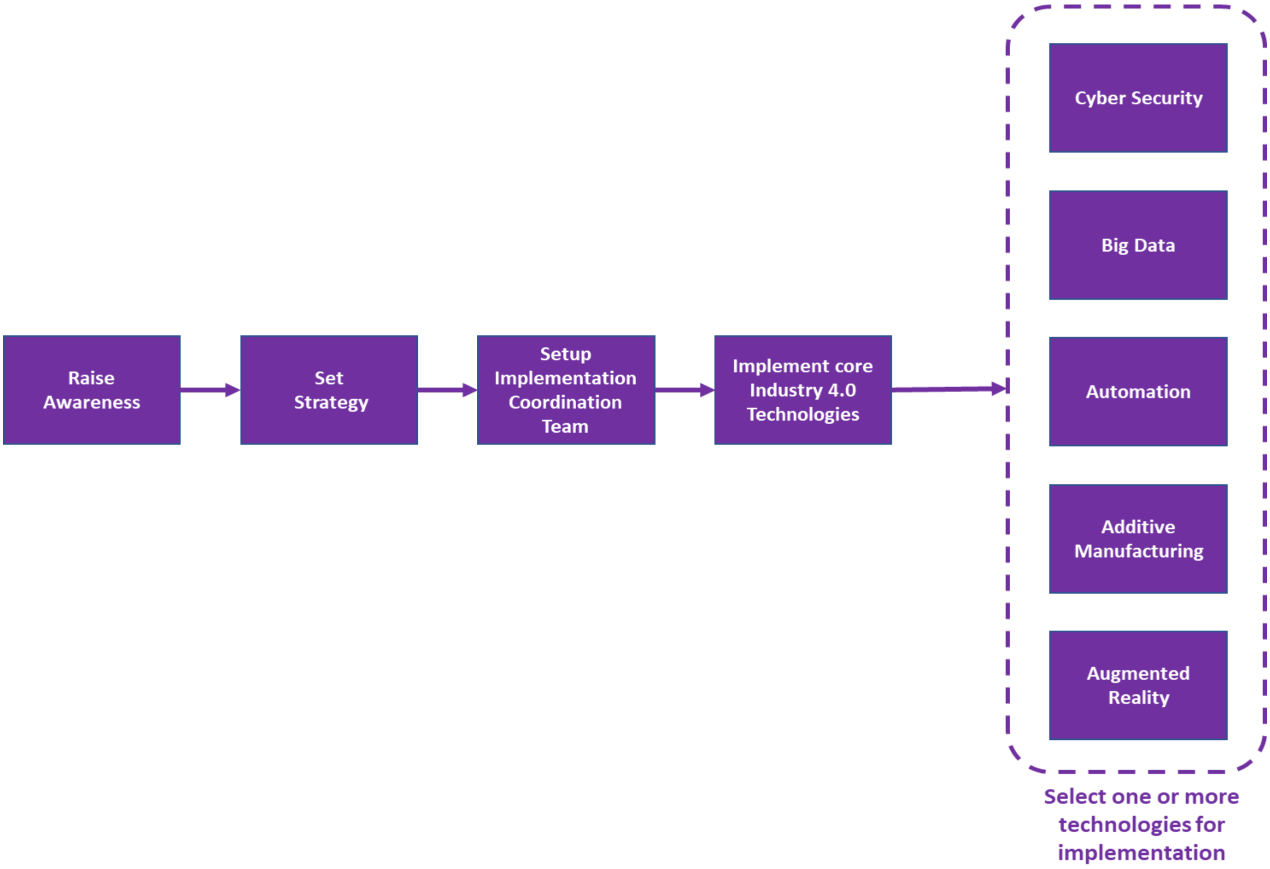


Figure 6.3 : I4EM Framework Implementation Model

6.7 Summary

This chapter focused on the validation of the proposed framework. As the framework is intended to enhance the UAE National Response Framework, it is critically important that the views of the stakeholders are used in the validation process. Following a meeting with each participant, a survey with fourteen (14) statements was used to capture their views on the framework and its components. The major concern was the lack of advice on the implementation. Consequently, a new component was added to the framework to highlight key stages of the implementation.

6.8 I4EM Final Framework

Figure 6.4 presents the final version of the I4EM Framework.

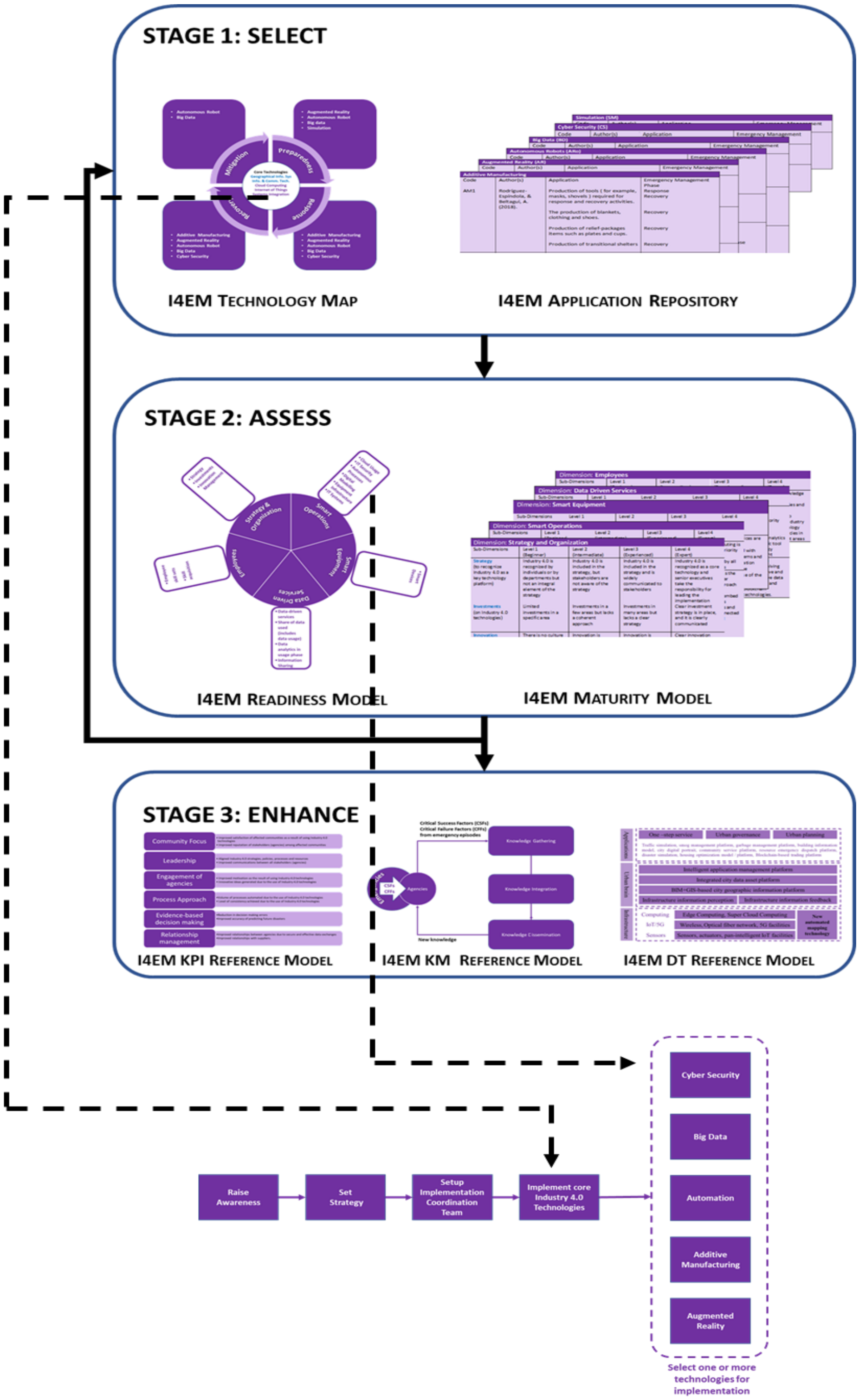


Figure 6.4: I4EM Framework – Final (Author)

Chapter 7 – Conclusions

7.1 Introduction

This chapter aims to draw major conclusions, state contributions to knowledge and propose potential future research work in this area. Research projects of this nature inherently have some limitations, and they are also discussed in the chapter. A brief summary of the rationale and the aim and objectives are provided at the beginning.

7.2 Rationale

As outlined in Chapter 1 and 2, natural disasters and man-made disasters increasingly affecting communities and livelihoods around the world. Emergencies caused by these disasters need to be managed efficiently and effectively for rapid recovery. For many years, technologies such as ICT and GIS have been used to improve responses to emergencies and other phases of the emergency management cycle. The inception of the Industry 4.0 concept has given new momentum to the emergency management communities. It provides a rich set of technologies that can be used to radically transform emergency management efforts. In the UAE, the National Emergency Crisis and Disasters Management Authority (NCEMA) is vested with managing emergencies in collaboration with other governmental agencies. A review of their National Response Framework revealed that there is no systematic approach in place to integrate new technologies. The review of literature further revealed that some Industry 4.0 technologies have been used in isolation, and there are no frameworks to facilitate the integration of Industry 4.0 technologies.

7.3 Aim and Objectives

The main aim of this work was to design and develop an industry 4.0 enabled framework for managing large scale emergencies in the UAE.

The stated objectives were

- Review systems for managing large-scale emergencies in the UAE and provide an overview of historical developments

- Conduct a series of interviews and a questionnaire to gather the current use of technologies and approaches to implement new technologies in the UAE National Response Framework
- Investigate the use of Industry 4.0 principles in the context of emergency management
- Develop an integrated planning framework based by assimilating strategies and technologies such as Industry 4.0
- Validate and refine the framework work and develop an implementation guide.

7.4 Research Methodology – Realising aim and objectives

As presented in Chapter 3, a systematic research programme was crafted to achieve the above-mentioned objectives. It began with a comprehensive literature review which justified the need for this research, and it enabled the researcher to develop a good understanding of the related research areas. The second phase of the research programme included a series of interviews and a questionnaire survey which revealed the current practices and aspirations of the UAE emergency management agencies. Information gathered from the literature reviews, interviews and the questionnaire survey was augmented with the review of existing Industry 4.0 readiness models to formulate the backbone of the I4EM framework. Finally, using the feedback from a group of professionals from the emergency management agencies, further adjustments were made to the framework.

7.5 Responses to the research questions

As stated in section 1.8, three (3) research questions were established in the quest for reaching the aim of the research programme. In this section, it is aimed to provide answers to the research questions.

<u>Research Question 1</u>*: What general enhancements are required to improve UAE National Response Framework?*

As the literature on the UAE National Framework is limited. It was necessary to conduct interviews and a questionnaire survey to identify the current gaps.

(a) From the questionnaire survey

- First responders are concerned about the usefulness of the information provided in the national framework.
- The information on integration/coordination appears to be somewhat weak.
- The role of technologies is acknowledged but there is a lack of understanding on how new technologies may enhance the national framework.

(b) From interviews

- Only a limited range of technologies are in use, mostly ICT, GIS and Robots. Interviewees believe that new technologies can transform the national framework.
- There is no provision in the national framework to capture and use knowledge from previous episodes.
- Due to the lack of KPIs, it is not clear whether new technologies introduced so far to improve the national framework have made a real impact.

These responses played a significant role in the development of the framework.

<u>Research questions 2:</u> What roles Industry 4.0 technologies might play in the enhancement of emergency management?

As reported in the section 5.3.2, many stand-alone applications of Industry 4.0 technologies in emergency management were listed and they formed the I4EM Application Repository. It was possible to identify several real or potential deployments for each technology. The technology with the least reported examples was a simulation. Currently. its prime use is training. However, if digital twins were to become a reality within the context of emergency management, simulation will be able to play wider role by analysing different scenarios in advance of real incidents.

The analysis of Industry 4.0 technology deployments in emergency management also concluded that that there are three technologies which should be in the core any implementation.

Internet of Things (IoT)

IoT is now widely used in many industries to gather data and control events. Given their widespread use, IoT technologies and networks can be used in every phase of the emergency management cycle.

Cloud Computing (CC)

Like IoT, Cloud Computing is also rapidly becoming the platform of choice for many applications. Given the lower hardware costs and the ability to access data and applications via the internet make, Cloud Computing the preferred platform for emergency management.

Systems Integration (SI)

Connected systems should be the backbone of any IT system. Given the range of stakeholders involved in emergency management, systems integration is seen as a central pillar of any development. It plays a critical role in avoiding the proliferation of disconnected systems, which lowers the responsiveness and effectiveness.

Research Question 3: *What are the best ways to embed Industry 4.0 technologies in the UAE National Response Framework?*

As reported in the Chapter 5, by using a systematic programme of work, this research work produced a framework to embed Industry 4.0 technologies in emergency management. Key steps included the development of:

- I4EM application repository and I4EM Technology Map
- I4EM Readiness Model and I4EM Maturity Model
- Three (3) reference models for KPIs, Knowledge Management and Digital Twins
- The overall framework amalgamates the above elements.

This framework enables the emergency management community in the UAE to systematically integrate and embed Industry 4.0 technologies to enhance its National Response Framework.

7.6 Contributions to the knowledge

Presthus & Munkvold (2016) outline thirteen (13) different types of research outcomes which can be considered as contributions to knowledge. This list includes new theories, models and frameworks.

The key contribution to knowledge is the development of the I4EM framework which provides systematic guide for the integration of Industry 4.0 technologies in the UAE National Response Framework (Figure 7.1)

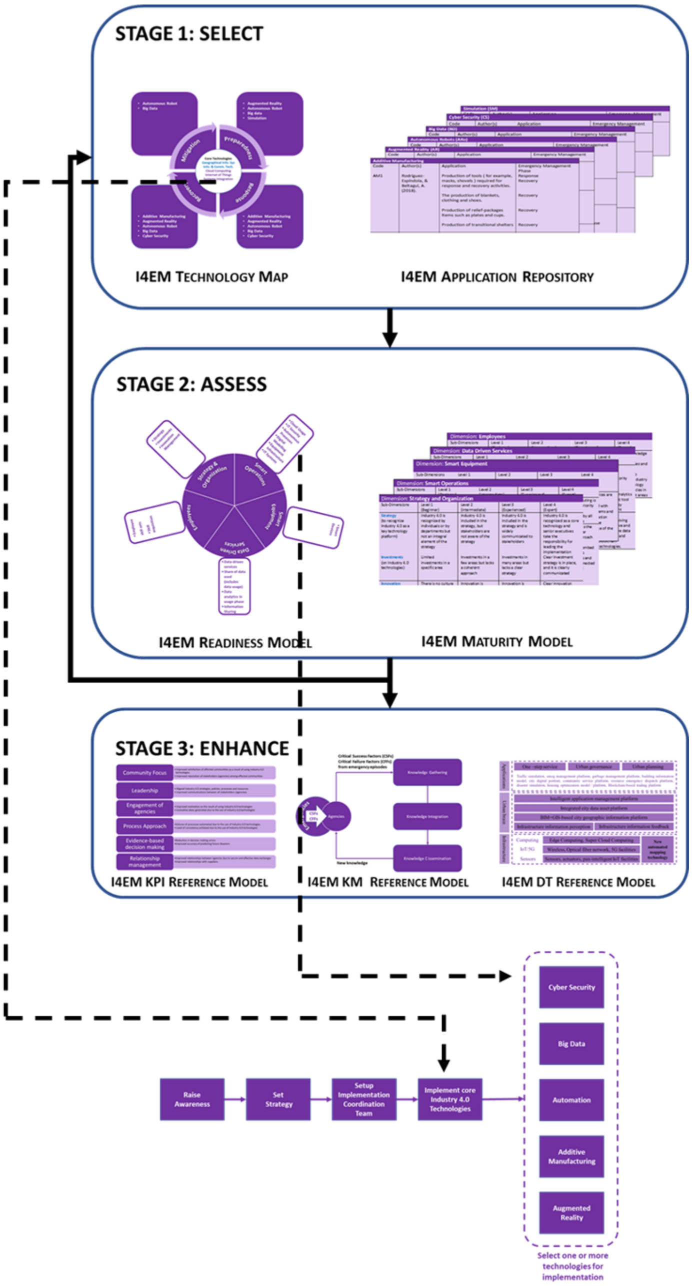


Figure 7.1: I4EM Framework

This is the first-ever attempt to develop a systematic framework for the emergency management field. Attempts to use Industry 4.0 technologies so far have been achieved in isolation, often with one technology at a time. This framework provides guidance to integrate Industry 4.0 technologies in a holistic manner. The development also made the following contributions to the body of knowledge in this field.

(a) **I4EM Technology Map** – This map illustrates the use of Industry 4.0 technologies in the four phases of the emergency management cycle (Figure 7.2)

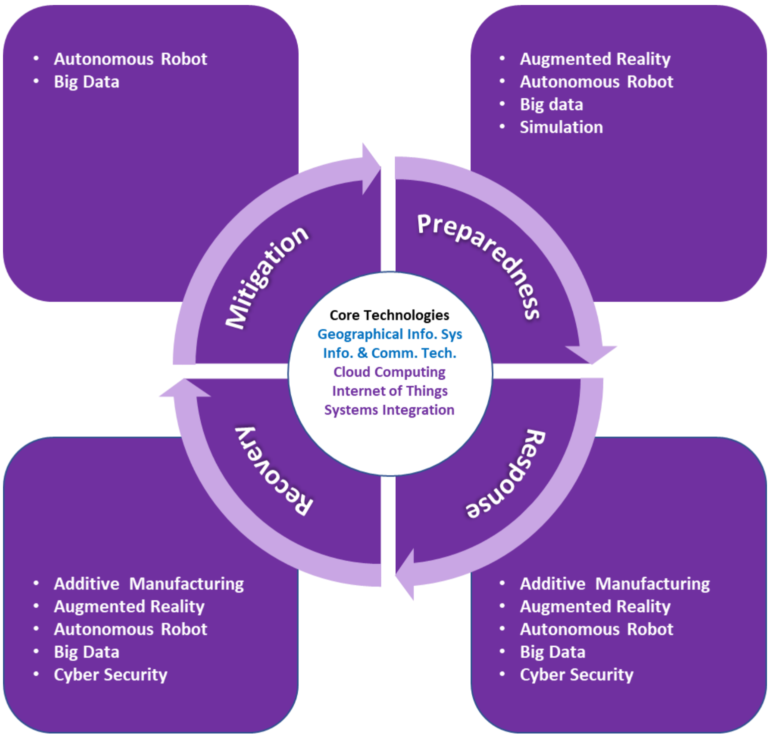


Figure 7.2: I4EM Technology Map (author)

(b) **I4EM Application Repository** – this provides an insight into the potential application areas of Industry 4.0 technologies in emergency management. Emergency management professionals can use this respiratory to choose applications for their areas (Figure 7.3)

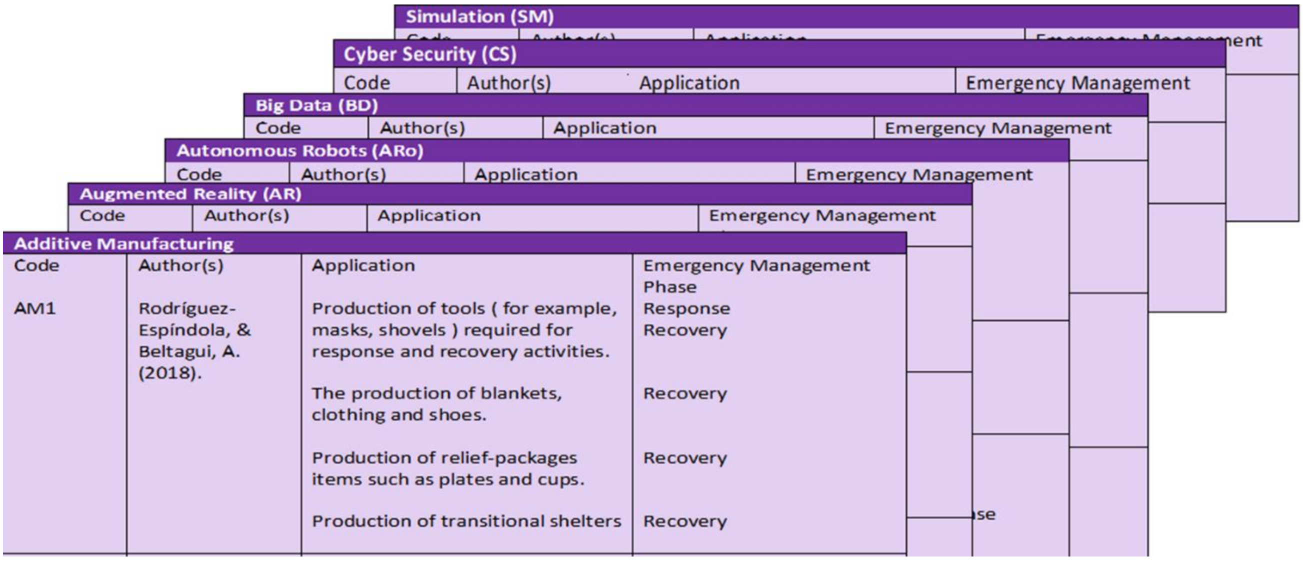


Figure 7.3: I4EM Application Repository

(c) **I4EM Readiness Model** – By systematically analysing well-developed readiness models for the implementation Industry 4.0 in the manufacturing sector, a bespoke readiness model was developed to assess the readiness in agencies involved in emergency management (Figure 7.4)

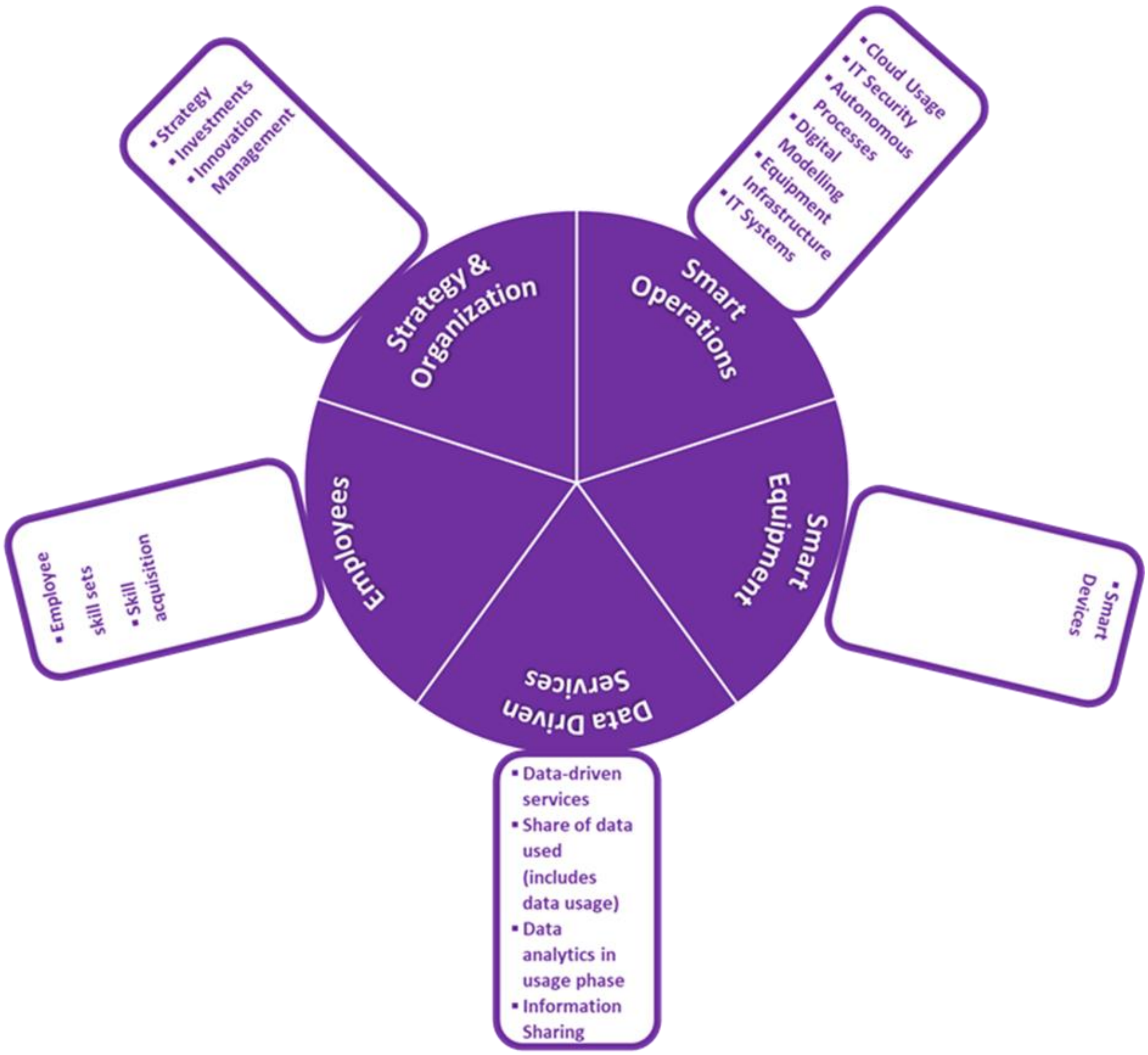


Figure 7.4: I4EM Readiness Model

(d) **I4EM Maturity Model** – This maturity model helps agencies to assess their readiness based on 15 sub-dimensions.

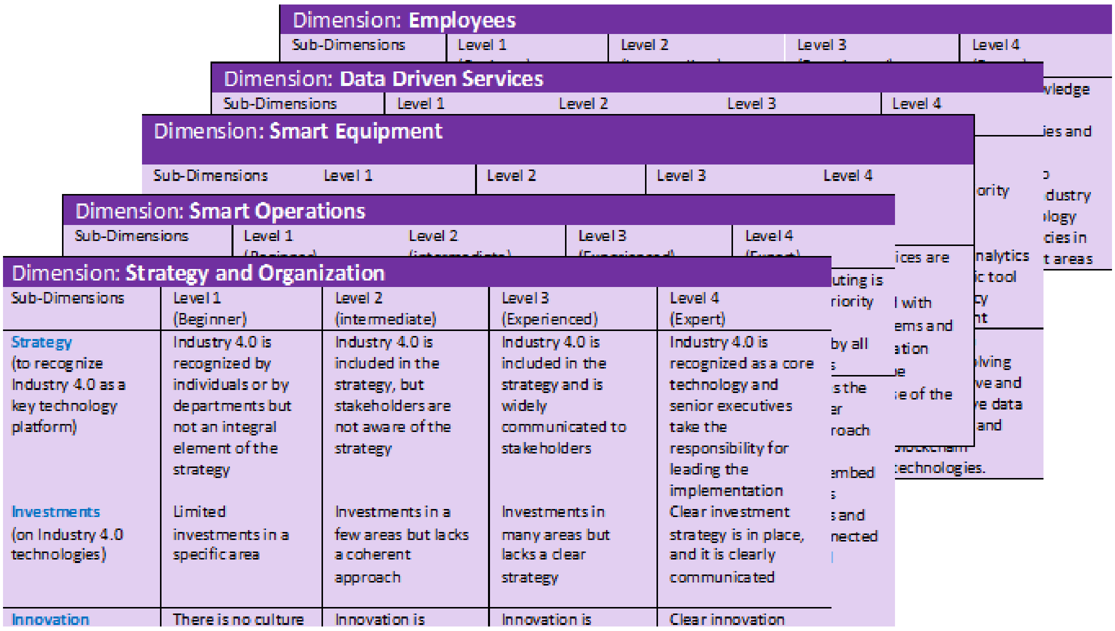


Figure 7.5: I4EM Maturity Model

(e) **Integration of three reference models** – Integration of Industry 4.0 in emergency management cycles should not be purely technology-focused. Industry 4.0 technologies enables agencies to exchange data and information securely and reliably; hence this opportunity should be taken to develop a comprehensive KPI model to assess the impact of Industry 4.0 technologies and create a knowledge management system to improve future emergency management efforts. Although realizing the concept of digital twins is years away, integration of Industry 4.0 technologies creates a robust foundation.

(f) I4EM Framework

7.7 Limitations

All research studies have limitations. It is important that specific limitations are recognized so that od some of them may be addressed in future research.

(a**) Scarcity of prior academic research –** Although there is an abundance of research publications on the use of Industry 4.0 in the manufacturing sector, there was only a very little publication on the use of Industry 4.0 across all phases of emergency management. Published literature mainly focused on the use of a single technology in one or more phases of the emergency management cycle.

(b) **Limited pool of experts in emergency management** – Given that the first edition of the UAE National Framework was released in 2013, there is only a limited number of experts on this subject. Some experts demonstrated a deep knowledge on the framework; however, a larger of pool of experts would have been beneficial.

(c) **Limited opportunities for validation** – Ideally, the use of the framework at least in a single instance, would have been immensely beneficial. As implementations take a considerable amount of time, this was not possible.

(d) Limited information on reference models – The primary purpose of reference model was to make the potential users of the framework aware that three elements, KPI, Knowledge Management and Digital Twins need to be considered concurrently.

7.8 UAE's Fourth Industrial Revolution (4IR) Strategy

In March 2021, the government of UAE formally launched a very ambitious strategy to strengthen the UAE's position as a global hub for the industry 4.0 technologies. It aims to promote the use Industry 4.o technologies in many sectors. Although emergency management has not been stated as a strategic area, several strategic areas can contribute to the development of Induystry4.0 applications in emergency management.

- Augmented Learning – can play a role in educating emergency management professionals on the use of Industry 4.0 technologies.
- Economic Security – particularly the use of the Blockchain technology.
- Intelligent Cities – this is the move toward smart cities, which is the fundamental building block of the development of digital twins.
- Open Additive Manufacturing – for rapid manufacturing in emergency management
- Intelligent Supply Chains – contributes to the development of intelligent humanitarian supply chains.

7.9 Recommendations for future work

The following future work is proposed to extend and explore the outcomes of this research work.

(a) Globally collaborative research with the UAE 4IR teams – Aligned with the strategy outlined in section 7.3, further research on the use of Industry 4.0 technologies in emergency management would be beneficial. It gives UAE the opportunity to become a leading advocate of using Industry 4.0 technologies across the globe in this vital area of emergency management.

(b) Developing a web-based repository to operationalize the I4EM Framework – The I4EM framework has many components, and further information on the components and their use would be useful to potential users. This is best achieved by developing a web-based platform.

(c) Further development of three reference models – As justified in Chapter 5, three reference models strongly complement the implementation of the i4EM framework. However, at this stage these are reference models, and they need be developed further to support their implementations. For example, in all three cases, it is vital to understand data requirements and how data going to be manipulated.

(d) Best practices from other nations – the nations with long experience in dealing with disasters and emergencies, for example the USA, UK and Japan, should have deployed various technologies. But the published material on these developments are not widely available. A project to gather examples from national agencies would be beneficial.

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Appendix 1

Section 1: Questionnaire

Technology enabled and integrated framework for managing large-scale disasters - Survey

Major Omar Alshamsi (Dubai Police Academy)

Sheffield Hallam University, United Kingdom

Dear Survey Participant

I am currently working on a programme research to develop a technology enabled and integrated framework for managing large-scale disasters in the UAE. I am seeking your support to understand the effectiveness of the current national response framework and to identify areas for improvements.

Thanks in advance for your support.

Major Omar Alshamsi

Section 1: Survey Participant Details

1.1 The level of understanding on the UAE National Response Framework (referred to as framework hereafter)

[ ] - High

[ ] - Medium

[ ] - Low

1.2 For how many years you have associated with the framework?

………… Years

1.3 What is your association with the National Response Framework?

[ ] - Contributor (contribute to the development and/or review of the framework)

[ ] - Enforcer (ensures others fully understand the framework)

[ ] - Coordinator (implementation of the framework in the event of a disaster)

[ ] - User (potential user of the guidance provided by the framework in the event of a disaster)

[ ] - Other (Please specify)…………………………………………………………………………………………………

1.4 What is the role of your organisation in the event of a major disaster?

[ ] - Frontline operations - dealing with victims of the disaster

[ ] - Coordination of frontline operations

[ ] - Coordination at higher levels of the government

[ ] - Other (Please specify)…………………………………………………………………………………………

Section 2: Risk Perception

2.1 What level of risk from natural hazards do the UAE face?

Type of Natural Hazard	Use following codes (A to F) to record the level of risk. **A** - Extreme risk, **B** - Major risk, **C**- Moderate risk **D** - Low risk, **E** - No risk, **F** - Not sure
Storm tide (combination tidal peak and raised water level associated with storm activity)	
Heatwave	
Flood	
Tornado	
Earthquake	
Landslip	
Erosion	
Tsunami	
Epidemic human disease	
Animal and plant disease	
Food safety threat	
Meteor/ space debris strike	

2.2 Which non-natural hazards do the UAE face?

Type of Natural Hazard	Use following codes (A to F) to record the level of risk. **A** - Extreme risk, **B** - Major risk, **C**- Moderate risk **D** - Low risk, **E** - No risk, **F** - Not sure
Civil disturbance/riot	
Terrorist attack	
Arson	
Sabotage of services	
Shooting massacre	
Information technology failure e.g. virus	

Bridge collapse	
Collapse of significant building	
Failure of critical infrastructure	
Hazardous materials contamination	
Transport accident (rail/road)	
Aircraft accident	
Marine accident	

Section 3 UAE National Response Framework

3.1 How do you rate the overall usefulness of the framework?

[ ] - High

[ ] - Medium

[ ] - Low

3.2 How would you rate the information available to emergency management activities in these categories?

Category	**A** – Exceptional, **B** – Good, **C**-Fair, D-Less than adequate
Emergency Governance (guidance to executives)	
Operational (guidance to emergency coordinators)	
First response (guidance to response teams and volunteers)	
Community (guidance to the public on how to prepare and respond to an emergency)	

3.3 How important are these sources of guidance on emergency management?

Source of Guidance	**A** - Very important **B** - Quite important **C**- Moderately important **D** -A little important **E** -Not important **F** -Not sure
International examples	
UAE standards	
UAE Government guidelines	
Local guidelines and legislation	
Internally developed procedures	
Samples and guidance from peers	

3.4. Effective emergency response requires tighter and effective <u>integration</u> between coordinating departments. How do you rate the information provided on the importance of integration in the framework?

[ ] – Exceptional

[ ] – Good

[ ] – Fair

[ ] - Less than adequate

Section 4: Science and Technology

4.1 Science and technology capabilities are essential for enabling the delivery and continuous improvement of national preparedness. How do you rate UAE efforts to use of science and technology in improving national preparedness?

[ ] – Exceptional

[ ] – Good

[ ] – Fair

[ ] - Less than adequate

4.2 The following science and technology capabilities may be used to improve national preparedness. How do you rate the importance of technologies listed below?

Science/Technology Capability	**A** – Very important, **B** – Fairly Important **C** – Important, **D** – Slightly Important **E** – Not at all important
Communication	
Data Sciences	
Automation	
Modelling	
Cyber security	

4.3 Social media plays an increasing role in how people communicate during major incidents. However, any fake news during these incidents could hamper rescuse efforts. How do you rate the following statements?

Statement	**A** – Very important, **B** – Fairly Important **C** – Important, **D** – Slightly Important **E** – Not at all important
All social media channels should be shut down during a major incident.	

UAE government should consider using social media to communicate with its citizens during a major incident.	

Section 5: Potential areas of improvement

5. 1 National Response Frameworks require regular reviews and improvements. State the areas that need improvements and any suggestions that you may have to improve them.

………

………

………

………

5.2 Any other comments?

………

………

………

………

Appendix 2

Evaluation of I4EM (Industry 4.0 for Emergency Management)

Dear Participant

First of all, thanks for agreeing to provide your expert feedback on the proposed framework.

As we discussed at our meeting, with the view to enhance the UAE National Response Framework, I embarked on a programme of research to investigate the potential use of Industry 4.0 in emergency management. I am seeking your feedback on the framework presented which encompasses four (4) key modules (Application Repository, Technology Map, Readiness Model and Maturity Model) and three (3) Reference Models (Key Performance Indicators, Knowledge Management and Digital Twins).

Your feedback will be immensely useful in the process of enhancing the model and its implementation.

Thank you in advance for your support.

Yours sincerely,

Major Omar Alshamsi

Feedback

Please state your views on the following statement by placing a cross in the appropriate column

	Strongly Agree	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**	**Cannot Comment**
S1. The overall aim the framework is clearly stated						
S2. The overall structure of the framework is easy to understand						
S3. Interactions between components of the framework are clear						
S4. The current technology map is a good representation of technologies used in the UAE						
S5. The application repository helps to understand of potential applications of Industry 4.0 technologies						
S6. The I4EM Technology Map helps to identify where Industry 4.0 technologies can be deployed within the emergency management cycle						

S7. The key dimensions identified in the I4EM Readiness model are appropriate and applicable						
S8. Descriptors provided for each sub-dimension to gauge the current level of maturity are adequate.						
S9. The I4EM Readiness Maturity Model helps organizations to plan implementation strategies.						
S10. The UAE Emergency Management communities regularly use Key Performance Indicators (KPIs) to measure the impact of new technologies.						
S11. The use of KPIs is essential in measuring the impact of Industry 4.0 technologies						
S12. The selected KPIs broadly covers the areas where the impact of Industry 4.0 needs to be measured.						
S13. Systematically managed knowledge about Critical Success Factors and Critical Failure Factors from previous disasters are immensely useful.						
S14. The concept of digital twins can play a role in emergency management						