Development of a geospatial information system specification for informal settlements

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It all starts here ™

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PREFACE

This dissertation was inspired by the appalling conditions many South African families live in. The difficult living conditions in informal settlements inspired the author to assist in making their lives better and safer. Many of the residents of informal settlements are children and some have already lost their lives to tragedy. A radio news report about children who had burned to death in their locked shack – sleeping alone with a paraffin lamp to keep them warm whilst their parents were away earning a living – was just one of the many shocking stories that made me realise I needed to use my knowledge and skills to help others live a better life.

The Midvaal Local Municipality Emergency Services welcomed my request to use their municipality as a case study and provided some background to the issues they face when responding to emergency situations within the Sicelo informal settlement. The input from Midvaal Local Municipality served as a baseline for this dissertation; their underlying problem of not having geospatial information for informal settlements under their control being the most critical issue.

As an electronic engineer, I decided to research solutions which lie within my field of study and to develop a tool to assist in providing the information the municipality required. The wish to develop such a tool was quickly laid to rest, given the short time span in which to do the research. I was guided to use my recently gained systems engineering skills to develop a system specification that would allow me to complete the research within the specified time frame.

In conclusion, the development of such a specification is seen as a first step towards developing a solution that may result in change in the way informal settlements are managed. It is my hope that this research paves the way to improving emergency response to the people most at risk to disasters and to hasten the development of informal settlements. The hope is that we will finally be able to achieve the millennium development goal of eradicating informal settlements.

ACKNOWLEDGEMENTS

In the name of God, the Beneficent, the Merciful.

All praise be to the Almighty, Lord of the worlds. Peace, blessings and salutations be upon his blessed servants.

Firstly I would like to thank God for blessing me with the ability and helping me to complete this dissertation. I would also like to thank my family for supporting me and encouraging me to complete this dissertation. Special thanks goes out to my wife who was instrumental to my success – the early mornings on weekends we both spent working on research whilst missing out on family gatherings and friend outings to get the research complete would not have been possible without your help and support.

ABSTRACT

In South Africa there are many informal settlements and due to the nature of such settlements, they are prone to various risks. The settlements are inherently poorly developed and lacking basic services and infrastructure for safeguarding against natural elements. In addition, these informal communities give rise to socio-economic issues. Municipalities face various challenges in managing informal settlements, including planning the development of housing and responding to emergencies. These challenges may be attributed to a lack of data regarding the informal settlement landscape and population.

The aim of this research was to determine the data that are valuable to the municipality and to specify a tool that collects such data and allows for the manipulation of the data in a manner that would assist municipalities in improving their service delivery to informal settlements.

The research contained within this dissertation discusses the background to the research, which includes several case studies of incidents within informal settlements. It is followed by a study of literature around disaster management, development of informal settlements, the South African government's role in the development of informal settlements, and the use of technology in disaster management. The basic theory on systems engineering is discussed, as a systems engineering approach was followed in the experimental design. In the experimental design the design of the system specification is discussed, which includes the development of input documents, identification of stakeholders and the structure of the system specification.

The specification was developed as a separate document to the dissertation and is included as Appendix A to this dissertation, as it is meant to be used as a separate document. The analysis of the specification is, however, included as part of the dissertation and the contents and results of the specification and the research are also discussed.

The development of a system according to the system specification will be of great benefit to municipalities, provided that they are involved in the development process and include their additional requirements; the specification is seen as a baseline with the minimum requirements. There may be several challenges in developing such a system, for example, the use of 3D-imaging hardware and software and the integration with other systems. Gaining the residents' approval and getting them to provide the required information may also prove to be a challenge for the successful implementation of such a system.

KEYWORDS

GIS for informal settlements, Geospatial information system for Informal settlements, Informal settlements development, Disaster management for informal settlements

ABBREVIATIONS

CODEV	- Cooperation and Development Center
FDS	- Functional Design Specification
GIS	- Geographical Information System
GISFIS	- Geographical Information System for Informal Settlements
GISSIS	- Geographical Information System Specification for Informal settlements
HDA	- Housing Development Agency
HUG	- High-res Urban Globe
IEEE	- Institute of Electrical and Electronics Engineers
MDG	- Millennium Development Goals
MES	- Midvaal Emergency Services
MLM	- Midvaal Local Municipality
MPD	- Midvaal Planning Division
NDHS	- National Department of Human Settlements
NUSP	- National Upgrading Support Programme
RDP	- Reconstruction and Development Programme
SBC	- Spot Building Count
SDS	- System Design Specification
SRS	- Stakeholder Requirement Specification
SS	- System Specification
WBS	- Work Breakdown Structure

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CHAPTER 1 INTRODUCTION

The population of South Africa's informal settlements has seen a gradual decrease over the last decade. Over a 15-year period there has been a 2.45% decrease in the number of dwellings in informal settlements from 16.04% in 1996 (Statistics South Africa, 1996) to 13.58% in 2011 (Statistics South Africa, 2012:63). In the period from 1994 to 2001, however, the population in informal settlements did not change significantly, despite the South African government relocating people to formal dwellings by providing almost 3 million houses during this time (Manuel, 2013).

In South Africa, the migration of people from rural to urban areas continues as people seek better lives and jobs. Johannesburg's population, for example, has increased by 1.2 million people between 2001 and 2011 (Manuel, 2013). These people generally cannot afford to pay for accommodation in built-up areas and therefore build informal housing in peri-urban areas using scraps of material available to them. The cycle of migration from rural areas to informal settlements and from informal settlements to Reconstruction and Development Programme (RDP) housing continues, and municipalities struggle to eradicate informal settlements. Informal settlements bring along additional risks and challenges for municipalities as well as emergency services.

The South African government is committed to formalising housing in the country, and eradicating informal settlements is one of the key steps in ensuring that they can fulfil their mandate. The government's RDP is a programme where the government builds low-cost housing for people without formal housing. The RDP housing programme is not without issues; some people who receive RDP houses complain about structural defects, the use of inferior materials (Masibi, 2012) and the allocation of housing to people who resell it illegally (Corruption Watch, 2012).

This study was based on the Sicelo informal settlement, which is located within the Midvaal Local Municipality (MLM) south of Johannesburg. Sicelo was chosen for this study as it is a relatively small, controlled informal settlement on which the tool could be developed and tested. Sicelo is unique as it was only established after the MLM had been established and so, whilst the general informal settlement population has decreased in South Africa, Sicelo has seen a rapid increase in population since 2001. Sicelo is home to about 7 200 people, with its population rising by 39% in a decade (Urban Genesis Management, 2010).

The Midvaal Planning Division (MPD) and the Midvaal Emergency Services (MES) were keen to assist in the study as they realised the need for such a system and saw the benefit that such a system would have on the way they would be able to do their tasks. Their support was instrumental in getting the research off the ground.

1.1 Background

Dwellings within informal settlements are built with little planning and no input from the local council. In the Sicelo informal settlement near the author's residence, new dwellings are built wherever there is land available. This results in a densely packed area that increases risks and challenges to the municipality. Many municipalities do not have access to mapping data for the informal settlements within their jurisdiction. Planning for future growth or upgrades to these informal settlements is difficult without access to a mapping solution which would provide valuable detail as to how to plan and better organise these areas.

Historically, informal settlements do not have access to electricity in every dwelling and so the people often use liquid fuels for cooking and heating. Residents of dwellings also commonly use candles to provide light in the dwellings. Many dwellings within informal settlements are built from wood and other flammable materials and with open flames in the them these dwellings catch alight easily.

While researching how emergency services operated, it was interesting, yet understandable, to find that the MES was located in the town centre of Meyerton, the largest business hub within the municipality. This central location enables the emergency services to respond quickly to most emergencies in the town centre and surrounding residential areas. Informal settlements, however, have been built on the outskirts of the town, placing them further away from emergency services. Emergency services experience impeded access to the informal settlements because, due to the lack of planning, dwellings deeper into the informal settlements have been built more densely than those on the outskirts of the settlements; shacks are not numbered so they are difficult to identify; and few roads are wide enough for fire trucks or ambulances to traverse. Water points are scarce, and installing them in the correct places has been difficult for the planning departments due to the lack of mapping data.

The dense nature in which these dwellings are built (The Housing Development Agency, 2012b:27) accelerates the spread of fires and at the same time impedes the rapid response that is crucial to contain fires – many homes and lives have been lost as a result. The MES's Chief Fire Officer explained in an interview that when an emergency call comes through emergency personnel arrange a meeting point with the caller, who then tries to guide them to the relevant location and the closest water point. Operating in this way wastes valuable time (Steyn, 2013).

The population of these informal settlements are entitled to basic and emergency services, but it is evident from the above that these services are not delivered at an acceptable level of quality and when lives are lost in informal settlements, municipalities should not make excuses as to why they could not respond in time. It is therefore vital that a solution is developed to assist municipalities in achieving their responsibility of providing these services to the population.

1.2 The Problem Statement

There is a lack of geospatial data for informal settlements in South Africa resulting in poor service delivery and emergency service response. A solution is required in order to improve services within informal settlements.

This study aimed to investigate tools available in the 21st century to develop a specification for a comprehensive tool, which would assist municipalities in planning emergency response and future upgrades in informal settlements. The tool would enable them to plan for their immediate needs as well as for future upgrades or disaster scenarios so that they would be better equipped in the case of disasters.

1.3 Research Objectives

The aim of this research is to determine what data could be used to improve municipal services to informal settlements and then to develop a System Specification (SS) for a tool that could gather, capture and present the data in a manner that would be beneficial to municipalities throughout South Africa.

The objectives of this research were:

- to research available literature regarding disasters that affect informal settlements as well as how technology can assist in the planning and development of informal settlements and in disaster management;
- to develop a Stakeholder Requirement Specification (SRS) that captures the needs of all the stakeholders;
- to develop a System Specification (SS) for a Geographical Information System for Informal Settlements (GISFIS), hereafter referred to as the Geographical Information System Specification for Informal Settlements (GISSIS);and
- to validate the SS against the SRS to ensure that the needs identified in the SRS are sufficiently covered by the SS.

1.4 Research Outline

The research is presented as a study divided into six chapters as well as appendices and references in order to meet the objectives of the study. The chapter division is presented below:

Chapter 1: Introduction

The first chapter introduces the field of study, which is followed by a discussion on the issues surrounding informal settlements. The background and purpose of the research are also discussed and the problem statement defined, with the aims and objectives providing direction for the study. Finally, an overview of the structure of the study is provided to guide the reader through the study.

Chapter 2: Literature Study

The second chapter of the study contains a survey of the literature around the topic of the study. This includes sources from journals, articles, theses by other students as well as government policies.

This chapter looks at literature available on how technology is being used as a tool for housing development and planning around the world and how various technologies are being used to assist in disaster management and planning for such disasters. The South African policy and government strategy linked to the areas of housing and disaster management are investigated in order to find possible solutions, as well as any relevant information that may be an input to find a solution to the problem statement.

Chapter 3: Experimental Design

The third chapter of this study deals with the design of the experiment that was performed in order to conduct the research. This chapter identifies the tools that will be specified along with the design requirements for these tools and the method used to benchmark or test the tools proposed as the outcome of the study.

This dissertation specifies the tools in the form of an SS with input from stakeholders recorded in a stakeholder requirement specification. This chapter describes how these documents are developed as well as the structure in which the specifications are developed.

The procedure to validate and verify the input documents as well as the SS is also discussed.

Chapters 3, 4 and 5 are very closely linked in this dissertation and a diagram explaining the link to the following chapters in terms of how the results are presented and analysed, is presented in this chapter.

Chapter 4: Experimental Results

As discussed in the outline of Chapter 3, Chapter 4 follows on to discuss the results and findings derived from the experiment designed in Chapter 3. This chapter presents only the data, not the results, as the results are discussed in Chapter 5.

Chapter 5: Analysis of Results

The results presented in Chapter 4 are discussed in Chapter 5 and the interpretations and learnings are presented as an outcome of the study. In this chapter, the SS is validated and verified against the input documents, stakeholder requirements and, most importantly, against the problem statement.

Chapter 6: Discussion and Conclusion

As the previous chapter determined the outcome of the research, the author moves on to Chapter 6, which is the final chapter of the dissertation. This chapter summarises the research by looking at the objectives of the research in light of the results presented in Chapter 4. The concluding paragraph makes recommendations based on this study's research and identifies areas that require additional research or investigation for possible future research.

Having covered the scope of the research and outline of this dissertation, the author will now delve into the literature review for this research, which will review and discuss the various topics of discussion around this dissertation. The author will investigate issues around planning in informal settlements, disaster management and development of informal settlements, as well as government's role in this development.

CHAPTER 2 LITERATURE STUDY

2.1 Introduction

This literature review presents three main areas of research relevant to the proposed project, namely, technology used in planning, technology used in disaster management and the South African government's policy on housing and disaster management.

It begins with an overview of how technology is being used as a tool to aid with housing and planning. Thereafter, it examines examples of how technology is used in the planning process around the world. Next, the review looks at how technology can aid in disaster management, before it investigates the South African policy and government strategy linked to the areas of housing and disaster management. Given that South Africa is a developing country, the review will also look at research conducted in other countries and will discuss the findings in a South African context.

2.2 Literature Review

Geographical Information Systems

Geographical Information Systems (GIS) is a special-purpose digital database that uses a common spatial coordinate system as its primary means of reference. The database is used to input and store geographical data which can then be retrieved, analysed, used for statistics or to provide reports in the form of maps, for instance (University of Colorado, 2014). The term GIS was first conceived by R.F. Tomlinson when Canada was developing a tool for map storage and manipulation as part of its rural development programme. Tomlinson defines the basic capability of a GIS to be a system that accepts and stores any location-specific information, namely any information that can be associated with an area, line or point on a map. He also notes that the effectiveness of the system depends on the quality of the data entered (Tomlinson, 1968).

Planning

Internationally, municipalities are moving towards using technological tools to aid their town-planning processes in order to develop so-called smart towns (Cooper; Carter, 2013; Smedley, 2013). These tools require inputs in the form of population and mapping data which allow the tools to function correctly.

In a study by Rumbach (2014) on the increased risk faced by new settlements, Rumbach identifies that whilst planning is done for formal infrastructure within new areas, informal settlements are generally overlooked. As a result, risks in formal areas are identified well in advance and mitigation measures are put in place to minimise the risk. This is not the case with informal settlements, which results in their having to face increased risks (Rumbach, 2014:123).

Through his in-depth research on informal settlements, Abbott has recognised the need for GIS to be a part of planning and the upgrade of informal settlements (Abbott, 2003). The City of Cape Town has also identified this as a need in a presentation at a Fire Safety Symposium (The City of Cape Town, 2013). In their presentation they highlight shocking statistics on the number of incidents they respond to, as well as the number of deaths fires cause in the informal settlements .

Delving into the City of Cape Town's presentation, it is clear that the issues faced by the MLM are not isolated to that municipality and it highlights the need to find a solution that can be rolled out to various municipalities. One of the issues discussed in the background to this dissertation in Chapter 1 is that of limited access to informal settlements. The City of Cape Town also notes the importance of planning roads through informal settlements to allow emergency vehicles to respond to fires quickly (The City of Cape Town, 2013). The presentation details similar issues to those experienced by the MLM and confirms the need for a GIS that would allow them to plan their services accordingly.

Municipalities need to be involved in the development phase of informal settlements as they are responsible for providing services to the people who live in their municipalities. Planning in the development phase allows municipalities to let people build their structures in a manner that will best enable service delivery by the municipalities to the people (Akhmata & Khan, 2011:59). For municipalities to plan effectively, they need to have data on the landscape of the informal settlement. There is currently very little mapping data of informal settlements available to municipalities, with only about 3% of existing informal settlements in South Africa having a shack count (The Housing Development Agency, 2012a). One of the outcomes of this study will specify a tool that would assist in addressing this information gap.

The importance of having data on the population of an area is highlighted quite clearly in the following example:

Nigeria is one of the most populous countries in Africa, but a large part of the country does not have geospatial data available. Scientists at DigitalGlobe have developed an algorithm called High-res Urban Globe (HUG), which uses computer vision to extract shapes from satellite image pixels that could indicate locations of human settlements. The data derived from this algorithm could be used to plan the distribution of vaccines, aid or plan an election (Barrington, 2014).

DigitalGlobe realised that whilst their algorithm produced data, they could not be sure of the accuracy of the data unless it was physically verified by humans. They took advantage of a crowdsourcing platform called Tomnod, which sends the individual pieces of data to people who have signed up to their service, who then verify the data. The result was that 50% of the data was found to actually have buildings in them (Barrington, 2014). This example highlights the importance of technology but also the risk of relying solely on computer data. The Nigerian program also demonstrates how important geospatial data is in order to plan the distribution of services to people.

The aforementioned example indicates how information on the population can be used for various purposes, be it planning elections or responding to disasters – in this example, they specifically mention vaccines and aid – which relates to using GIS in emergency relief efforts and disaster management.

In South Africa, GIS data is already being used by some state enterprises for planning purposes. Eskom's Spot Building Count (SBC) system, developed by the CSIR, searches and identifies buildings from satellite imagery. This allows Eskom to identify areas that are electrifiable or not; it provides insight into the current power situation and allows Eskom to view the backlog, as well as to identify trends or changes in areas (Breytenbach, 2010). This data provides Eskom with valuable information which allows them to plan for future expansion (providing electricity to more people) and to effectively manage areas where there are rapid changes to the landscape (Breytenbach, 2010).

Disaster Management

In terms of literature on technology and its use in disaster management, very little is available from a South African perspective, but there are several authors who have discussed the issue using international examples. Nouali, et al. has compiled various examples of how technology has been used in disaster management, including much work on the use of technology to assist in recovery efforts post natural disasters. There are also technological innovations that assist emergency management services in planning for disasters, such as early warning systems or simulations that provide a picture as to what to expect in such situations so that the emergency services can train and prepare accordingly (Nouali *et al.*, 2009). The limitation, however, is that many of these technologies or innovations are only able to assist in planning efforts within urban areas where the landscape is known.

In many countries prone to natural disasters, there are various early warning mechanisms in place to alert people to upcoming threats. South Africa is somewhat behind in this field and have few early warning systems in place, probably because the country does not have major natural catastrophes such as earthquakes, typhoons, tornadoes, cyclones and tsunamis occurring regularly. This may have contributed to the country being lax in investing in early warning systems for natural disasters such as floods and fires.

The wild fires in the Cape Peninsula in March 2015 called attention to the need for such early detection and warning systems in South Africa. Many people had to be evacuated from their homes as the fires approached – it destroyed some farms and homes and took the lives of two people (Davis, 2015). With early detection systems in place, the fire may have been contained or the damage may have been limited.

In Australia the CSIRO have used different technologies to predict disaster scenarios. The organisation has developed models to simulate flood scenarios such as those that might be caused by dam breaks in China and upstream of Perth. By overlaying the geographical data, such as housing and population, of an area, they are able to produce a clear picture of the likely damage should such scenarios materialise. They are also able to plan where civil engineered structures should be placed to mitigate such damage (CSIRO, 2012:5).

Using simulation technologies requires that the input data be accurate. Should a similar simulation be done in South Africa it would be highly probable that there would be informal settlements affected by a flood due to them being built in low-lying areas. These technologies would allow municipalities to analyse scenarios to determine the likelihood of floods affecting settlements. This would enable them to decide whether structures are required to divert the flow of water away from a settlement or to prioritise the relocation of that settlement.

The CSIRO have furthermore developed a social media monitor to create emergency situation awareness . This software analyses feeds from the Twitter social network and, based on unusual behaviour in Twitter feeds, alerts people to possible emergency situations. The associated Vizie application assists in mining this data based on predetermined words that were used during past emergency situations. An abnormal count of these predetermined words over a five-minute period triggers an emergency notification which rescue officers can use to quickly respond to such issues (CSIRO, 2012:12). With smartphone penetration on the increase in South Africa and social networks such as Twitter seeing a growth of 129% in 2013 (World Wide Worx, 2013), technologies such as these can be instrumental in enabling South African emergency services to be proactive and to respond to situations appropriately.

In the South African context, informal settlements have a high risk of being affected by disasters due to the nature in which they are built. Wekesa, Steyn and Otieno argue that the materials used to build the dwellings are generally of a poor standard, as the people building these dwellings cannot afford durable building materials (Wekesa *et al.*, 2010). In their study they evaluated several technologies used to build structures and evaluated them against their protective measures against the elements. They then proved that the better technologies used to build the structures, in terms of technical and environmental suitability, are unaffordable to these people. In South Africa, we find that many informal dwellings are built with pieces of wood, plastic, tin and even mud. These materials place the dwellers at risk to various elements. Wood and plastic are fuel for fire and mud dwellings are at risk of being washed away during heavy rains.

The Cooperation and Development Center (CODEV) describes disaster risk reduction as one of the major challenges of the 21^{st} century – especially for the vulnerable population who live in makeshift homes and are most at risk in disaster situations. The CODEV also identifies the role of technological innovation, such as early warning systems, and the subsequent impact and number of people affected by such disasters (CODEV, 2014).

Development

Following on from disaster management to development, the eThekwini Municipality has conducted a study on four existing informal settlement sites on the possibility of developing those settlements into formalised housing on site (Ethekwini Municipality, s.a).The municipality came to the conclusion that the land topography is unsuitable for on-site development due to the steep slopes on which the informal dwellings are built that make access to the settlements difficult. This conclusion also draws attention to further risks such settlements face due to topographic factors. The CODEV specifically mentions research on landslide risk reduction through the use of GIS, risk mapping and assessments (CODEV, 2014) as part of their undertakings in disaster risk reduction. This is part of their focus since there are many informal settlements around the world that have developed on slopes that are unsafe or unsuitable for occupation, which have resulted in many deaths and loss of property (Diaz, 1992).

There are several efforts throughout the world to investigate methods to eradicate informal settlements. Target 7.D of the Millennium Development Goals (MDGs) (United Nations, 2013) aims to improve the lives of 100 million slum dwellers.

The South African government is committed to developing informal settlements and various departments within the government have initiated programmes such as the National Upgrading Support Programme (NUSP) to develop informal settlements. Whilst the main aim of the NUSP is to upgrade every informal settlement within the country, the government has acknowledged the need to improve living conditions in informal settlements for the time being (NUSP, 2013). In 2010, the National Department of Human Settlements (NDHS) commissioned the CSIR to update the Human Settlements Atlas 2009, the aim of which is to provide a spatial quality of life index (productive life; shelter; safety; health) (Van Rooyen, 2010). These programmes all drive the Human Settlements Vision 2030, which aims to eradicate a housing backlog of over 2.1 million houses that will provide accommodation and services for approximately 12.5 million people (Government Communications (GCIS), 2013/2014).

The Department of Human Settlements (2015) has identified priority areas in order to achieve their goal of sustainable human settlements. They are:

- Accelerated delivery of housing opportunities;
- Access to basic services;
- More efficient land use; and
- An improved property market.

Looking at the priority items listed above, it is evident that Government requires a multi-pronged approach in order to achieve their development goals. Government needs to develop and provide basic services such as water, sanitation, electricity and sociocultural amenities simultaneously to achieve their goal of providing sustainable human settlements (Department of Housing, 1995).

The use of GIS can be of great assistance when Government identifies possible places for relocation of people to lower risk areas. Tomlinson (1968, p.202) describes the ability of the search feature in a GIS to identify suitable locations based on given criteria – the GIS system could identify sites near to sanitation facilities, for example. This would be of assistance when the government is required to provide temporary shelter to people in emergency situations, like they did during the xenophobic attacks (Rondganger, 2015) or when relocating people after shack fires in informal settlements.

Having discussed the literature around the various aspects of informal settlements, planning and disaster management, the literature around systems engineering is now discussed to allow the author to make use of systems engineering principles in the experimental design for this research.

Systems Engineering

In order to develop the GIS for Informal Settlements, the author will follow the systems approach as described in systems engineering. The International Council of Systems Engineering (INCOSE) describes the field of systems engineering as follows:

> ‘an interdisciplinary approach and means to enable the realisation of successful systems. It focuses on defining customer needs and required functionality early in the development cycle,

documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem.' (INCOSE, s.a)

As per this description, the systems approach to solving a problem can be considered as a holistic approach, taking into consideration all of the auxiliary requirements to provide a solution that resolves the problems the customer identified.

As part of the systems engineering process, INCOSE also references ISO/IEC 15288, which defines a six-stage systems engineering life cycle. Table 2.1 describes the six stages below:

Table 2-1: Systems Engineering Life Cycle

LIFE CYCLE STAGES	PURPOSE	DECISION GATES
CONCEPT	*Identify stakeholders' needs* *Explore concepts* *Propose viable solutions*	*Decision Options* *– Execute next stage* *– Continue this stage* *– Go to a preceding stage* *– Hold project activity* *– Terminate project*
DEVELOPMENT	*Refine system requirements* *Create solution description* *Build system* *Verify and validate system*	
PRODUCTION	Produce systems Inspect and test [verify]	
UTILIZATION	*Operate system to satisfy users' needs*	
SUPPORT	*Provide sustained system capability*	
RETIREMENT	*Store, archive, or dispose of the system*	

(INCOSE, 2006:3.4)

This dissertation fulfils part of the first two stages of the systems engineering life cycle, namely the Concept and part of the Development phase. The contents of this dissertation, however, reference and define items from later stages of the life cycle.

According to INCOSE Systems Engineering Handbook the system requirements form the basis for the design, manufacture, test, and operations of the system. Any changes made to the requirements at a later stage during the development cycle may result in significant cost impacts (INCOSE, 2000:128). As a result, the SRS is developed at the earliest possible stage.

System reliability

Considering that computer-based systems are prone to failure, it was necessary to investigate the factors that affect downtime of such systems. According to McFarlane (in Bigelow, 2011), as much as 75% of downtime incidents are the result of human error, most of which is attributable to a lack of training or poor planning. Schuknecht (in Bigelow, 2011) concurs with McFarlane by attributing 73% of downtime incidents to human factors and agreeing that training plays a big role but, in addition, he identifies poor maintenance practices as a contributing factor.

Verification and Validation

In order to understand the context in which this dissertation uses the concepts of verification and validation, the reader needs to understand the theoretical aspects of these terms.

According to Enfocus Solutions (2011), ‘Validation is the process of confirming the completeness and correctness of requirements’ Validation also addresses each individual requirement to ensure that the requirements are:

- Correct – accurately states a customer or external need
- Clear – has only one possible meaning
- Feasible – can be implemented within known constraints
- Modifiable – can be easily changed, with history, when necessary
- Necessary – documents something customers really need
- Prioritised – ranked as to importance of inclusion in product
- Traceable – can be linked to system requirements, and to designs, code, and tests
- Verifiable – correct implementation can be determined by testing, inspection, analysis, or demonstration (Enfocus Solutions, 2011).

Verification, on the other hand, is the process of ensuring that the final product is developed according to the requirements documented within a design specification (Enfocus Solutions, 2011).

In the context of an SS, which is the product of this dissertation, both validation and verification are applicable. Validation is applicable to the requirements specified within the SS as well as to the input documentation. Verification is only applied to the system that is developed using the SS and is regarded as part of the quality assurance process.

Conclusion

There are a number of possible uses for GIS in planning, disaster management and development. There are also a number of available solutions for various individual requirements relating to geographical information.

Touching on the theoretical aspects of systems engineering, the author used the life-cycle approach in developing the system that will be discussed in the following sections.

In the next section the author will look at the constraints and requirements for consideration in developing the SS for the proposed system.

CHAPTER 3 EXPERIMENTAL DESIGN

This section describes the design considerations that were taken into account to develop the Geographical Information System Specification for Informal Settlements (GISSIS). The previous section discussed various examples of the use of technology as a planning and disaster management tool. The researcher incorporated the learnings from these examples into the design specification in order to provide a robust tool that may be used for all informal settlements.

For the purpose of this dissertation the researcher chose a system specification as a means to specify the GISSIS, as opposed to focussing on developing a hardware and software solution or design specification.

3.1 System Specification

The System Specification (SS) is a document that describes the functionality of the entire system. The SS provides the minimum requirements that the final solution needs to meet in order for it to be acceptable. The SS is therefore developed at a high level and detail design specifications for subsystems are required to form a System Design Specification (SDS) to ensure that functional or discipline specific requirements are captured. Considering the life cycle process discussed in Chapter 2.2, the SS forms part of the early stages of a system's life cycle. The Stakeholder Requirements Specification (SRS), which is an input document to the SS, ties into the concept phase of a system and the SS takes the system from the concept through the design phase and describes the system until its retirement.

In developing a specification, it is important to note that specifications need to be clear, precise and not open to interpretation, to prevent the purpose of the specification from being lost. This is especially important since the end user may hold the development company to the specifications listed in the SS and, if these specifications are not met, the developer may be subject to legal proceedings.

The SS, which includes the software and hardware specifications, provides the requirements for developing the system and subsequently the actual hardware and software. These specifications are discussed in the SS input documents in section 3.1.2 below

Since the GISFIS contains multiple components (hardware/software), the development of an SDS that provides detailed requirements for the design of the other components of the system, namely, hardware/software etc. is also required in order to fully define the GISFIS. This research, however, does not include the development of such an SDS, as it does not provide a solution to the defined problem but rather defines how the solution should be implemented.

3.1.1 Stakeholders

For the GISSIS, the stakeholders were identified to be the MLM, the MES, the MPD and the author.

As the author has done the research, this study regards the author as a key stakeholder; even though he is the developer of the documentation that is to be validated and verified..

3.1.2 System Specification Input Documents

An SS requires input documentation. The input documentation that is typically required is an SRS. Generally, the stakeholders are involved in developing the SRS. However, the lack of GIS information for informal settlements is the problem statement of this dissertation and the research outcome was for the author to provide a research-based solution. Subsequently, the author developed the SRS using the problem defined in the opening chapter and the literature survey of this study. The development of the SRS is discussed below.

3.1.2.1 Stakeholder Requirement Specification

The Stakeholder Requirements Specification is a document that describes the minimum requirements that the system needs to meet. This section of the dissertation discusses the development of the SRS for the GISFIS. It was important to cover every requirement in the SRS, as it forms the basis for the SS.

The requirements developed in this section are based on (but are not restricted to) the needs that were identified by the MLM during the initial interview with the Chief Fire Officer of the MES (as well as from examples discussed in the literature review). The SDS focusses on two areas of the system which are to be developed, namely, the hardware and software.

3.1.2.2 Work Breakdown Structure

Using the SRS, a Work Breakdown Structure (WBS) is developed. The developer breaks down the system using a WBS to allow for development, prioritisation and integration of the system in a controlled manner. The WBS is developed after determining all of the components of the GISFIS and organising the various components into a structure so that costs and work can be allocated accordingly to the various components. The resulting WBS is presented as a visual structure.

3.1.3 System Specification Structure

The experimental results section (CHAPTER 4) of this dissertation discusses the development of the actual SS. This section discusses the structure which will be followed in the development of the SS.

Given that the SS is used to develop the system, it is important to define the scope as well as how the system will operate. The structure of the SS is based on the IEEE 29148:2011 (Institute of Electrical and Electronics Engineers Inc., 2011). The introductory paragraphs of the SS will define the purpose and scope of the specification and will give an overview of the GISSIS. The GISSIS system will be split into two main sub-systems, namely:

- Hardware
- Software

The interfaces between the departments within the municipalities are discussed as a note to the specifications to provide additional background information, which will allow the system developer to fully understand the requirements of the specification.

Following the general overview of the GISSIS, all the documents referenced by the SS will be listed to ensure that end users of the SS may determine the source and reasoning behind various specifications. Thereafter, the study discusses the general specifications of the GISSIS. The discussion includes detailed specifications of hardware and software relating to the GISSIS. Security requirements for the system will also be defined for both hardware and software to ensure the system is protected from theft and cyber security threats.

Once the GISSIS requirements have been completely defined, the interface requirements of the GISSIS system are discussed. This will then be followed by the system maintenance requirements, training requirements and other requirements as per IEEE 29148:2011. This includes the system life cycle as defined by INCOSE which was discussed in section 2.2

Whilst the structure of the GISSIS will follow IEEE 29148:2011 very closely, there are sections that are not applicable to GISSIS and will not be included in the development of GISSIS.

3.1.4 Validation and Verification

Based on the theory discussed in Chapter 2.2 Literature Review, specifications need to be validated to ensure that the requirements listed are actually required, achievable and, if achieved, would meet the stakeholders' needs. Validation is first done on the stakeholder requirements as this is an input document to the SS and is usually compiled together with the stakeholders. In the context of this dissertation, the Midvaal municipality provided a problem which was discussed in the opening chapter and research was done to find a solution to their problem. The research forms the basis for the SRS. As such, the SRS was developed out of the research that was conducted and then validated against the research, indicating the links to the literature or the problem statement as required.

Once the SRS has been validated and the development of the SS is complete, the SS is to be validated against the SRS to ensure that the stakeholder requirements are conveyed to the developer through the SS.

The validation of the SRS allows for the verification of the final product (i.e. GIS systems developed according to the GISSIS against the SS, which in turn means that the final product meets the requirements of the stakeholders. In the context of this dissertation, the verification of the final system that is developed using the GISSIS is excluded, as the development of the system falls outside the scope of this dissertation. However, the system that is developed for the municipality will be verified by the municipality using the GISSIS as a guide prior to acceptance of such a system.

Conclusion

The first two chapters of this dissertation are the input documents used in the development of GISSIS, as it states the problem and available literature which feed into the SRS and the SRS feeds into the SS. The design specification for specific components (hardware, software, etc.) is to be developed as future research since the development of such detailed design specification documents was not required as research on the problem statement of this dissertation.

This chapter discussed the procedure for developing the SS. The discussion will continue in the following chapter when the results are obtained and presented. The flow chart in Figure 3-1 hereafter summarises the flow of activities for the next chapter:

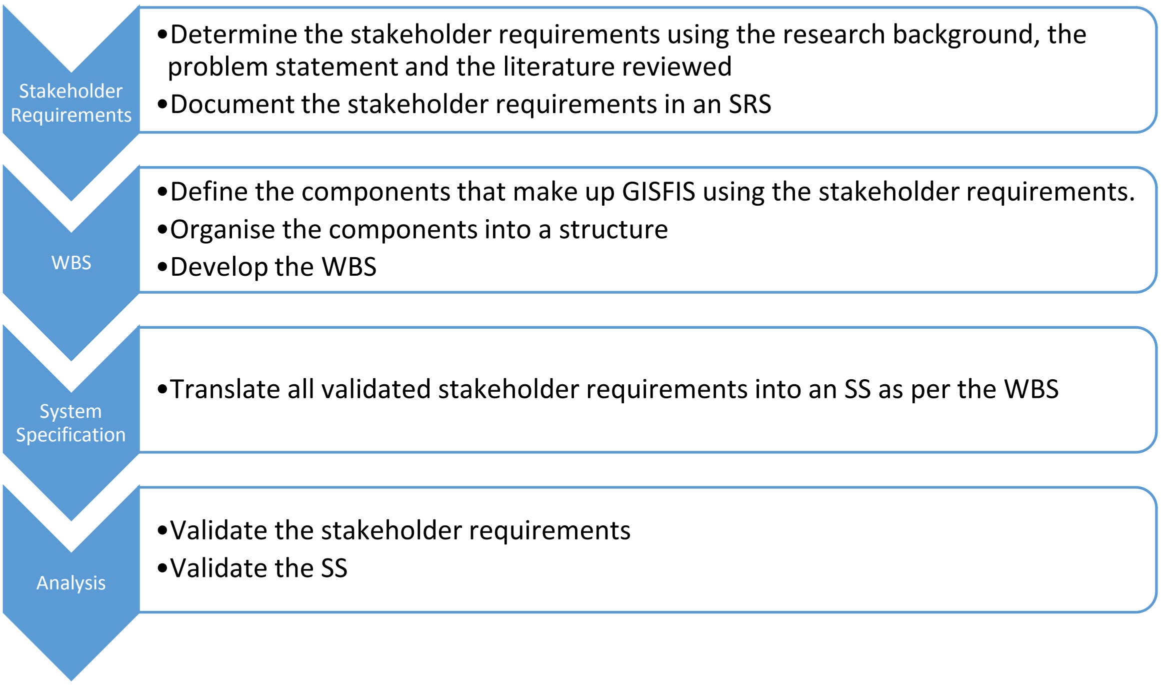

Figure 3-1: Summary of Experimental Procedure

The system which is to be designed will only work if the end user (which is the municipal personnel) uses the system as intended. People are generally reluctant to change, and implementing a system that would not be used would be wasteful. To ensure that the system will be used, it is important that the system is designed as a user-friendly interface and that it provides the end user with what they require. The system should assist the end user by simplifying tasks and improving efficiency.

To ensure that this is possible, the system will need to be designed correctly, tested thoroughly, and personnel will need training on the system before it goes live.

CHAPTER 4 EXPERIMENTAL RESULTS

The previous section discussed the procedure for conducting the research as well as the order in which the research should be conducted, beginning with the stakeholders' requirements to developing a WBS and ending with the development of the SS. This chapter presents the results that were achieved by following the procedure described in Chapter 3. The structure of the presented results follows the flow of the procedure described in the previous section in Figure 3-1, allowing the reader to be engaged in the thought process that the author followed as he conducted the research.

4.1 Stakeholder Requirements Specification

The previous section presented the procedure for working toward the objectives of this design. Using the procedure outlined in Chapter 3, the development of the stakeholders' requirements began.

The stakeholder requirements specification is a list of validated requirements and as such would not fit in with the flow of this dissertation. It has been included in Appendix B - Stakeholder Requirement Specification (SRS) for the reader to peruse as additional information. In the appendix each requirement is discussed and the rationale behind selecting that item as a requirement is given below the requirement. The requirements are validated and where there were comments regarding the validity, the comments are included.

The SS will focus on two areas of the system that will be developed, namely the hardware and software.

4.2 Work Breakdown Structure

Using the SRS, a Work Breakdown Structure (WBS) was developed. The system is broken down using a WBS to allow for development, prioritisation and integration of the system in a controlled manner. The WBS was developed to guide the development of the SS as it is one of the inputs into the SS. The WBS also allows for activities to be allocated to costs and managed according to a schedule. The WBS for the GISSIS is given below in Figure 4-1:

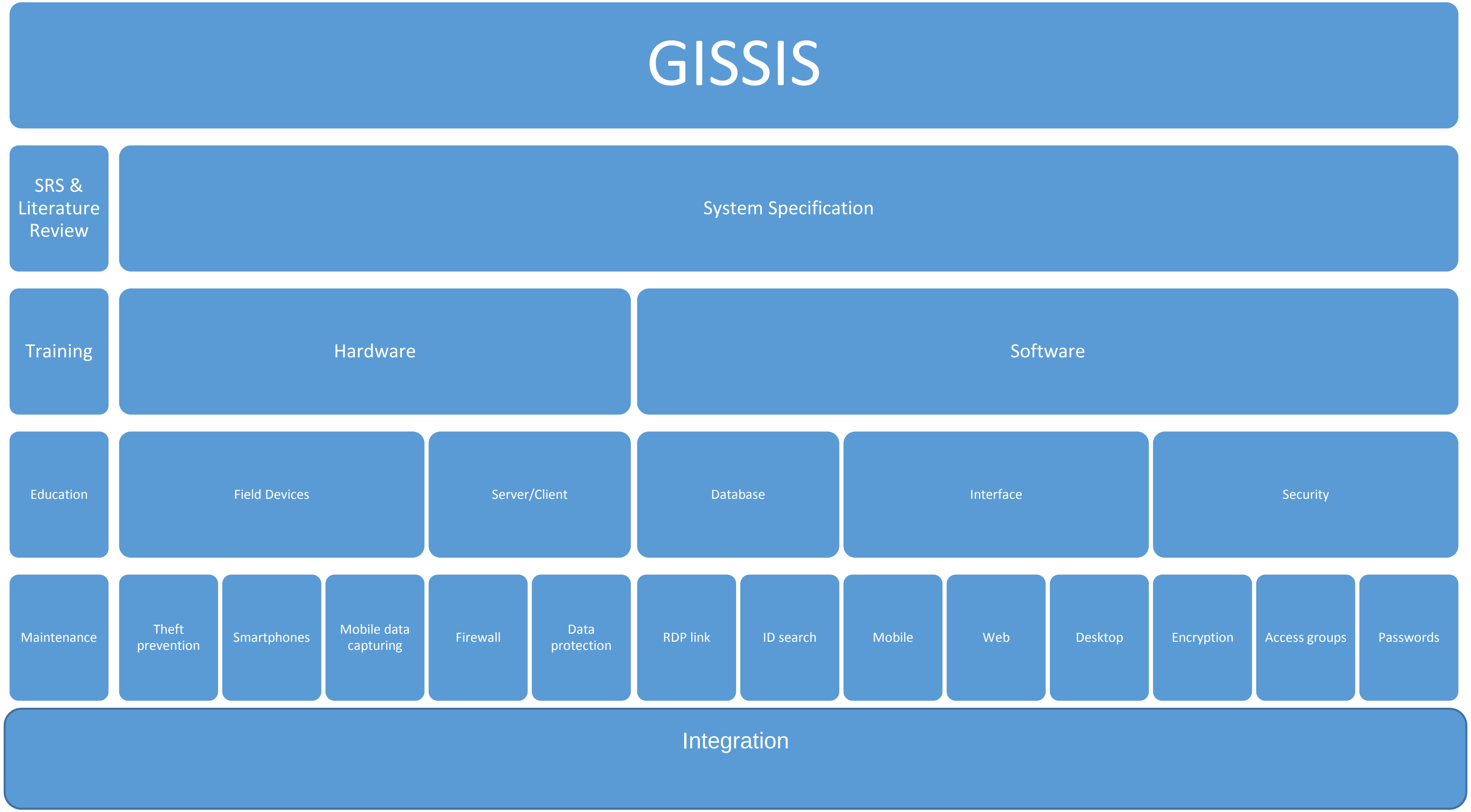

Figure 4-1: Work Breakdown Structure

4.3 System Specification

With the WBS developed, the breakdown of the required work was defined to ensure that all of the aspects of GISSIS would be covered. The defined stakeholders' requirements and the developed WBS allowed for the SS to be developed. The SS was developed as Appendix A to this dissertation as the SS is a document which others may use separately from this dissertation.

The contents of the SS covered a variety of aspects of the GISFIS at a level that allows the developer to develop the system using their standards and procedures but also defines the basic requirements that a GISFIS should have. Specifications developed in such a way allow for the system to be as open as possible to ensure that future integration with other systems is possible and that municipalities are not tied down to a single vendor. This leaves room for municipalities to consider using third parties to maintain the system. This will ensure that the system vendors do not develop unfair practices by overpricing the support offered to municipalities, as the maintenance of the system will be awarded to the most cost effective, technically-able company.

Due to time limitations in the development of the SS, some sections of the SS were not developed in as much detail as other sections of the SS. Municipalities may update the SS prior to them going out on tender to system developers to allow for additional or new requirements to be incorporated into the initial SS.

In the next section, the specifications that make up the SS will be validated as an analysis of the results obtained. This is performed against the requirements developed in this section (included in Appendix A) and against the problem statement.

CHAPTER 5 ANALYSIS OF RESULTS

In the last chapter the experimental design procedures were followed as per the flowchart in Chapter 0 in order to obtain the results. In this chapter the results are analysed to extract the benefit from the results, which allows the author to determine the value of the results achieved through this research.

5.1 Validation of SRS

As explained in the experimental design chapter, the method used to analyse the results is the validation of the specifications against the stakeholders' requirements as well as against the problem statement of this research.

The validation of the stakeholder requirements is done against the literature review as well as input received from Midvaal Emergency Services (MES). The validation is presented as a matrix with the input from MES and the literature survey listed on the right and the associated requirement on the left.

Table 5-1: SRS Validation

Stakeholder Requirements Specification	Input Requirements
1 – GIS information	1.2 The Problem Statement This is the baseline requirement for a GIS tool – namely, to capture geospatial data and to display the results.
2 – Collaboration between departments	Fourth paragraph of Chapter 1.1 Background Second paragraph of Chapter 2.2 Literature Review – Planning Since the tool will be used by various departments within the municipality, collaboration between the departments is required. Planning departments may be responsible for the data capturing and manipulation whilst emergency services need to provide input on emergency infrastructure and possible emergency routes. There may be a need for emergency services to report errors as well.
3 – Staggered development	Municipalities may not have the money to implement the entire system in at once. They may be able to make capital available over a period of time and so the development of the GISSIS may need to be staged (for example, adding add-on features like simulation packages at a later stage, once all data has been captured correctly and verified).
4 – 3rd party integration	The municipality has existing databases that contain information about the population. The GISSIS should be able to use or give information to other programs to make the solution value-adding.
5 – Support	Many vendors provide solutions, get paid and disappear, leaving the municipality in limbo. By ensuring that they are contractually bound to provide support, the municipality will enjoy the full benefit of the GISSIS.
6 – Expansion	First and fourth paragraph of Chapter CHAPTER 1 Introduction Due to the number of people living in informal settlements growing in

	certain areas as well as the number of new informal settlements, the system needs to allow for such expansion without municipalities having to pay additional development fees.
7 – Data handling	Based on 6, the municipality may need to search for specific data across areas. The results need to be displayed and filtered accordingly.
8 – Existing systems	Linked to 4, the municipality may need to overlay urban areas onto informal settlements for a better overview of their landscape.
9 – Open source	Open-source software ensures that the environment remains vendor independent. In the event that a specific developer cannot continue development (if the developer goes out of business, for example) the municipality would be able to appoint another to continue development.
10 – Training	Fifth paragraph of Chapter 3.1.3 System Specification Structure The municipality does not have such a system in place and end users will need training in order to use the system effectively.
11 – Availability	First paragraph of Emergency Systems in Chapter 2.2 Literature Review. The system is to be used to respond to emergencies within informal settlements. If the system experiences downtime emergency services' response time cannot be optimised, and the extent of damages may increase dramatically due to delayed and impeded response. .
12 – Speed	Following on from 11, the system will be used to respond to emergencies within informal settlements. If the system is slow, it is likely to result in delayed emergency response time, and the extent of the damages may increase dramatically if the emergency do not respond in time.
13.1 – Future informal settlement hotspots	Fifth paragraph of Planning in Chapter 2.2 Literature Review. Open areas near or within urban areas can become an informal settlement if not managed correctly. If the municipality is able to identify these locations, they may put measures in place to monitor and be part of the planning process in these areas.
13.2 – Data	Sixth paragraph of Planning in Chapter 2.2 Literature Review.

capture	The ultimate outcome is to eradicate informal settlements. Capturing population information within the informal settlements allows the municipality to link this data to the RDP housing list so that they may track the flow of people to formalised housing.
13.3 – Restricted data access	Due to the system holding confidential public information, only authorised personnel will have access to sensitive data. .
13.4 – Links to other databases	Linked to 7 and 8, data searches will retrieve results from other relevant databases to facilitate linking of data .For example, other information linked to an identity number could be linked to an RDP housing allocation.
14.1 – Emergency infrastructure	If the emergency services personnel are aware of the emergency infrastructure in the area it will allow them to respond faster and more efficiently to all emergencies. Knowing where the closest water point is, for example, is crucial to timely and efficient response.
14.2 – Lack of infrastructure	Linked to 14.1 above, this will allow the municipality to install such an infrastructure in order to improve service delivery
14.3 – Location id	Based on information provided by MES, it was difficult to locate the caller in an emergency. The solution should provide innovative ways of locating the point of the emergency.
14.4 – Routing	Roads in informal settlements are sometimes non-existent due to people building informal dwellings wherever there is space. At times, large fire trucks cannot get to the source of the fire due to accessibility issues.
14.5 – Vehicle routing (navigation)	Vehicle routing will take accessibility into account and can provide alternative routes to certain emergency response vehicles, as necessary. A wide fire truck, for example, will not be able to traverse narrow roads and may be unable to access an area by the same route police vehicles are able to.
14.6 – Call centre access	The system is designed to improve the services provided by emergency services and it is therefore crucial that they have access to the system through the call centre.
14.7 –	Emergency services will report obstructions on the provided routes to the

Obstructed routes	central call centre. The call centre should then be able to log the issue on the system so that the relevant department that can address the issue.
14.8 – Event tracking	Event tracking will allow the municipality to determine the most common types of incidents in a certain area and help improve planning and emergency services in that area.
14.9 – Event reports	Based on 14.8, the system will assist emergency services to determine high-risk issues in an area and help them to plan and respond in a way that can prevent recurrence of such incidents.
14.10 – Early warning	First paragraph of Disaster Management in Chapter 2.2 Literature Review. If the system can detect the start of a fire and report it, emergency services can respond before people see it and get to report it.
14.11 – Simulation packages	Fourth paragraph of Disaster Management in Chapter 2.2 Literature Review. This will allow municipalities to purchase a particular simulation package such as a fire or flood simulation package.
14.12 – Simulation types	Based on 14.11 Based on the risks identified in an area, a specific simulation package is developed for that scenario.

In the table above, the stakeholders' requirements are listed together with the rationale for each requirement. Considering the theory on verification in Chapter 2.2 Literature Review, each stakeholder's requirement needed to be examined to ensure that the requirements are actually achievable and measurable. Putting each listed requirement through that filter, it was found that the following requirements could not be defined because they would not pass through the verifiability filter:

Table 5-2: SRS Validation issues

9 – Open source	This requirement is not achievable as most of the developers make use of proprietary code to develop their systems. The only possibility in this case is that the interfaces to the system are well defined such that 3rd parties

	can easily interact with the system developed.
12 – Speed	The stakeholder requirements state that the system shall be fast, irrespective of time of day or demand on the system. This statement cannot be verified as the word 'fast' is a subjective term and cannot be measured.

Looking at Table 5-1, it is evident that the requirements listed as stakeholder requirements are clearly derived from the opening chapter of this dissertation as well as from the literature review, as the requirements listed are easily traceable back to the relevant sections. Considering that the opening chapter provides background on the problem and the literature review investigates other problems that municipalities may be faced with as well as solutions, the SRS can be considered as a well-defined document which includes all of the stakeholder requirements. In Table 5-2, the stakeholder requirements that could not be validated were highlighted to ensure that the stakeholders were aware of the reason as to why these requirements would not be achievable. Even though the above requirements could not be validated, these requirements were considered in the development of the SS although it was implemented in a way that would not achieve those requirements precisely. This is demonstrated in the validation of the SS against the SRS.

5.2 Validation of System Specification

The SS was developed after the validation of the SRS, which was followed by a validation of the SS against the SRS. This is provided in Table 5-3 below:

Table 5-3: System Specification Validation

Stakeholder Requirements Specification	System Specification
1 – GIS information	4.2.1.1
2 – Collaboration between departments	4.2.2 i
3 – Staggered development	3.2 g
4 – 3rd party integration	3.2 h, i, j
5 – Support	6.1

6 – Expansion	2.3 c, 3.2 g
7 – Data handling	3.2 i, j
8 – Existing systems	3.2 h
9 – Open source	4.2.4 a
10 – Training	6.2
11 – Availability	6.1.1
12 – Speed	3.2 d
13.1 – Future informal settlement hotspots	4.2.2 h
13.2 – Data capture	4.2.1, 4.2.2 a, b, c
13.3 – Restricted search results	4.2.1.5
13.4 – Links to other databases	3.2 h, i, j
14.1 – Emergency infrastructure	4.2.1.4
14.2 – Lack of infrastructure	4.2.2 v
14.3 – Location id	4.2.2 s
14.4 – Routing	4.2.2 p
14.5 – Vehicle routing	4.2.2 p
14.6 – Call centre access	4.2.1.6
14.7 – Obstructed routes	4.2.2 p
14.8 – Event tracking	4.2.1.6
14.9 – Event reports	4.2.1.6
14.10 – Early warning	3.2 k
14.11 – Simulation packages	3.1.1

14.12 – Simulation types	3.1.1 b

Based on the validation that was conducted in Table 5-3 above, it was noted that all of the stakeholders' requirements may be achieved should the developer adhere to the SS as the SS is validated against the SRS.

The table above contains a few of the system requirements which were listed to indicate how the SS was validated against the SRS. However, there are many more requirements that were listed in the SS that have not been discussed. In the following paragraphs, several important specifications are discussed in further detail to provide an understanding as to why the requirements were included in the SS.

5.3 Analysis of System Specification

In the SS, requirement 2.3 a on the applicability of the system states that the system is designed for informal settlements within South Africa. As per the Millennium Development Goals (MDG), there are millions of slum dwellers around the world – this specification focusses specifically on South Africa, as the South African government has existing policies which assist in the development of informal settlements. Due to the time constraints under which the author was placed, the author was unable to investigate policies from around the world relating to informal settlements. Therefore, it may be that the specifications could be used to develop such a system for use elsewhere, but the author of the specification takes no accountability for the use of such a system outside the borders of South Africa.

Requirement 2.3 c and e in the SS talks about additional requirements that the end user may have which may include additional functionality to GISFIS. These additions may apply specifically to the design specifications for the various modules of GISFIS as the end user may, for example, require additional design documentation. Whilst the addition of such requirements open up the GISFIS to scope creep, it is necessary to include such requirements due to the ever advancing technologies that are available. The purpose of the GISFIS is to improve service delivery to informal settlements, and new technologies may render some specifications of GISFIS obsolete. These requirements ensure that the GISSIS document remains current for as long as informal settlements exist. The detail design requirements also need to be developed prior to the development of GISFIS. Here again, the author of GISSIS was unable to include such detail requirements due to the given time constraints and such development is regarded as future work. Where mention of such aspects of the system is made, it is deemed that such a component is an integral part of the GISSIS and needs to be developed prior to the development of GISFIS.

Requirement 3.1 h in the SS refers to the existence of formal housing within informal settlements. Such a scenario, whilst seemingly non-existent, is in fact a reality and therefore such a case requires specific mention to ensure that system developers do not exclude such properties from GISFIS. Formal housing in such a scenario may include brick and mortar houses which may or may not have plans approved by the municipality.

One of the more important features of GISFIS is the simulation add-ons that are to be provided as required. Requirement 3.1.1 in the SS makes mention of the various disaster simulation scenarios that are required to be included as part of GISFIS. The nature of such requirements stems from the manner in which each of the disasters affect informal settlements. The effects of such disasters is largely dependent on the topography – a fire, for example, will spread upwards in a valley whilst a flood will cause more damage to lower lying areas. A medical emergency, on the other hand, is generally at a single point and the simulation would need to account for response times or the routes available for ambulances.

Requirements under 3.2 in the SS refer to the system capabilities of GISFIS and aims to specify some of the requirements that could not be validated in the SRS. The manner in which these requirements were handled was by providing a numerical value to contextualise the speed of the system into something that can be measured. This allows the system to be verified during testing to ensure that it meets the specified requirements. The population size was selected based on the understanding that the largest informal settlement in South Africa does not have a population of more than 20 000 people (The Housing Development Agency, 2012a).

Section 4 of the GISSIS describes the functional requirements of the GISFIS system. These requirements define the functions that the various components of the GISFIS system perform. The general requirements listed under this section include requirements that the developer may need to consider or provide prior to beginning development of the system.

The functional requirements of the GISFIS system is further broken up into the hardware and software-specific requirements. These requirements are in no way as detailed as they would be in a design specification but they were included to provide the minimum requirements to define the GISFIS system. The specific hardware and software design requirements should be developed further prior to the GISSIS being handed over to a developer to develop the system. These requirements also guide the developer of the design specifications to develop those specifications in a way that meets the author of the GISSIS' intent. Some requirements which the GISSIS' author deemed to be of importance such as relational information in databases were included to ensure such a requirement would be implemented. Since GISFIS aims to take advantage of the information available from multiple databases such as the RDP housing database, one to one relationships are important as this ensures there are unique identifiers in each database. The GISSIS also asks for the developer to document the development of GISFIS in a detailed manner so that this information may be used in future, either for debugging or future development.

Under the functional software requirements, the author chose to include certain fields of information in the various databases. The inclusion of such information was in no means to specify the detail design requirements of such databases but rather to ensure such information is available as the information may be required to allow for the various simulation scenarios. Under the dwelling information database the author included the type of material that was used to build the specific dwelling, as brick houses are stronger and more resistant to various hazards than wooden dwellings, for instance. The author included an emergency-log database in order to meet the stakeholders' requirement that reported incidents be recorded according to type.

With the inclusion of a mobile field device, there were several considerations that needed to be taken into account prior to specifying the requirements for such a device. In South Africa the crime rate is high and taking an expensive mobile device into an area where there is much poverty increases the risk of theft of such a device. There is even a risk whilst the device is a kept overnight at the municipality offices or whilst on charge during the day. Due to the risk of theft, several security features were included in the device to ensure that if the device is stolen the perpetrators would not be able to access any of the data and the municipality could try and recover the stolen device using the built-in tracking mechanism. Provision was also made for the use of a smartphone as a field capture device. This would reduce the cost of development, as a custom device would not need to be manufactured. However, using smartphones increases the risk of theft and damage and it is therefore not preferred.

In terms of the server, client and network hardware, the aim was to specify the minimum requirements and to allow the municipality to use their existing IT departments to specify the hardware requirements. As such, the requirement for GISFIS developers is to ensure interoperability between their systems and existing municipal infrastructure. Specific requirements were provided for redundancy of power supplies and network infrastructure since the system is used for emergency response purposes.

Finally, the use of Google's open-source Project Tango technology was included as a requirement, as the technology has potential in the mapping of informal settlements. Project

Tango uses multiple sensors to create a 3D image of an area. The initial idea was to take a 360-degree photo outside each informal dwelling to allow for a ‘street view experience’ for both the planning and the emergency services departments. This is possible using an android device with a camera that takes a photo-sphere picture (360-degree photo) and assigns a GPS coordinate to it. The multiple photo–sphere images are then stitched together to create a ‘street view experience’. Project Tango is still in its infancy, but it has the backing of Google, who has called on developers to bring forward ideas on where this technology may be beneficial (Google, 2015).

The system interface requirements discuss the general requirements relating to how the system interacts with other systems. Again, there is no detail specified, as municipalities across the country use different systems. The detail design specification which is to be developed is expected to provide for detail on how such interfaces will interact.

The operational requirements expect the developer to provide the maintenance requirements of their system. However, the municipality’s IT department will manage the system maintenance, which allows them to perform whatever maintenance is possible internally. The important aspects of maintenance though, is the system reliability which is specified to be very high due to the system’s role in emergency response. The spares requirements are important since custom hardware is developed for the GISFIS system. Since batteries are considered to be the component which fails most often in the lifetime of portable electronic devices, the availability of such spares and a low cost of the replacement is considered crucial. The GISSIS therefore specifies that batteries should be replaceable with batteries used in popular smartphones to ensure continuous availability of such spares.

Personnel using the GISFIS system require training in order to use the system correctly and to gain maximum benefit from it. For this purpose, the end users require a training manual, training material and courses to be developed with the system. The system developers will be responsible to provide training. The training detail requirements should be developed further but fall outside the scope of this dissertation. It is to include training interventions such as courses or workshops among other training requirements.

The SS furthermore covers several requirements relating to the system security and the IT requirements of the GISFIS. These requirements are necessary to ensure that the system is protected against the various security risks that the system is exposed to. The IT requirements of the municipality are included as an additional measure to ensure that the system is protected and functions optimally. The GISSIS also specifies certain documentation requirements to allow the IT department to understand the inner workings of the GISFIS system. By ensuring that the documentation is available, the IT department can assist users having difficulty with the program and debugging issues. They will also be able to decrease downtime as the system would be well defined using the documentation provided and they would not need to waste time understanding how the system operates.

The SS discusses the system life cycle to give developers an overview of how the system will operate throughout its life. This allows developers to consider events that may occur at a later stage and plan for such events in the development of the system. The GISSIS also includes some requirements relating to the procurement process such as schedule requirements and whilst these are not comprehensive requirements, these requirements are seen as over and above the municipality's internal procurement process requirements.

5.4 Conclusion

In this chapter the research results were analysed to extract more information and to understand the results. The results were validated against the various inputs into this research and against documents developed as part of this research which form the SS input documents. The validation process described in Chapter 3.1.4 Validation and Verification was followed in this chapter to achieve the outcome of having a validated SS. Furthermore, the requirements listed in the SS were analysed to provide an understanding of the contents of the SS.

The final chapter discusses the research results to determine whether the SS achieved the aim of this research, namely, to determine the data that is required to improve municipal services to informal settlements and to specify a tool that assists in capturing and manipulating such data.

CHAPTER 6 DISCUSSION AND CONCLUSION

Thus far, this dissertation investigated the specified problem and the literature surrounding it, along with current solutions that are used globally. Thereafter it discussed the method of executing the research, followed by the presentation and analysis of the research results.

Having conducted the research and analysed the data, the author needs to conclude whether the specified research objectives have been achieved and if the research that was conducted succeeded in providing a deeper understanding and solution to the problem.

6.1 Discussion

Looking back to Chapter 1.3 Research Objectives, the following objectives were listed in order to conduct this research:

- To research available literature regarding disasters that affect informal settlements as well as how technology can assist in planning, development and disaster management in informal settlements.
- To develop a Stakeholder Requirement Specification that captures the needs of all the stakeholders.
- To develop a System Specification for a Geographical Information System for Informal Settlements, namely the Geographical Information System Specification for Informal Settlements.
- To validate the System Specification against the Stakeholder Requirement Specification to ensure that the needs identified in the SRS are sufficiently covered by the SS.

In Chapter 2.2 Literature Review, various technologies which assist in disasters, as well as those used in planning and development, were discussed. It was found that many of the technologies have been successfully implemented in areas where the landscape is known. The study gave examples from South Africa where technology was used to estimate the number of informal dwellings, such as Eskom's SBC, but it was also noted that DigitalGlobe found that relying on satellite data is not possible due to the high number of false positives their system identified as buildings. As a result, Eskom's SBC may also be providing false positives or for that matter false negatives, which means that the data could be unreliable.

On the other hand, there are successful cases such as in Nigeria where the availability of population data allows for planning of elections and for the distribution of medication. The incorporation of technology into development was also touched on, specifically with regard to how this would assist in the development of informal settlements.

The SRS was developed after completing the literature review, using the problem statement and the literature that was researched as input into the SRS. This allowed the development of a holistic document outlining the requirements for a system which would assist in defining the GIS landscape for informal settlements. It was important that the SRS was developed using the literature review as an input as it allowed for the inclusion of existing technologies that have been proven to work.

The SRS was then validated against the source documents using a table format to ensure that all of the stakeholder requirements were valid.

Using the validated SRS, the GISSIS was developed, which outlines the requirements for a complete GIS system (GISFIS), which would allow the capture of GIS and population data and allow the data to be manipulated and reports to be generated.

Finally, the GISSIS was validated against the SRS to ensure all of the stakeholders' requirements were captured within the GISSIS.

In completing the objectives of this research, the question as to whether the GISFIS would solve the problems faced by the municipality and, more importantly, provide a solution to the problem statement of this research remains to be answered. As the GISFIS system has not yet been developed, it would be difficult to prove the value provided by such a tool. However, if one considers a system developed exactly as per GISSIS, it is possible to conclude that the correct use of such a system will provide the municipality with geospatial information of informal settlements which is stored in a database. This will allow the municipality to manipulate and draw reports from such a database. Based on this, one may also answer the question as to whether this provides a solution to the problem statement.

The problem statement states that there is a lack of geospatial data for informal settlements resulting in poor service delivery. The provision of GIS data which is made possible by the GISSIS provides the solution to the first part of the problem statement. However, it is important to note at this stage that the term 'geospatial data' is a broad term and the definition of such data as per GISSIS may differ from the data required by municipalities. Whilst the GISSIS is validated against the SRS, the SRS was based on the research done and input from one municipality. As a result of this, the author may not have covered all types of geospatial data and this may result in the GISSIS providing insufficient data in other municipalities. However, an SS provides the minimum requirements and should another municipality require additional data, they would need to include such data in their requirements to the system developer.

The problem statement also states that the lack of geospatial data plays a part in the poor service delivery to informal settlements. As noted in the Nigeria case study discussed in the literature review, the availability of population data allows governments and municipalities to plan the distribution of aid and resources based on the population within the area. Whilst the Nigerian case study does not cover all types of services provided by municipalities, the GISSIS includes several other technologies. These include route planning for emergency vehicles, the location of emergency equipment and utilities within informal settlements, and simulations, to name a few, which if used correctly and maintained will provide tremendous benefit and improved service delivery to informal settlements. Again, features that are not included in the GISSIS but are required by municipalities may be added to the requirements provided to developers.

The aim of the research was also achieved in that the research looked at the various types of technology that is used and specified the data requirements in order to implement the technologies discussed. These requirements were put together in the form of a specification (GISSIS) which defines all of the GIS requirements for informal settlements.

The implementation of such a system in the Midvaal Local Municipality would allow for the improvement of the service delivered by the Midvaal Emergency Services team as it would provide them with optimal routes to use when responding to an emergency. Since the operator will have information regarding the population living around the emergency, it would be easier to determine the number of people affected by an emergency should there be a need to relocate people. In terms of emergency response teams, their work would be made easier since the operator would be able to guide them to emergency utilities such as water points, whereas previously they would have had to look for such utilities once they arrive at the scene.

There are, however, some shortcomings in the proposed system which are important to note. The GISSIS defines fields in the population database which the population may not be willing to provide and this may affect the integration of the GISFIS into other systems. One of the most important fields is the identity number of residents as this field is used as a link to residents' information on other databases such as the RDP database. In order to gain acceptance by the population educational seminars are proposed in GISSIS as well as the employment of locals to promote the use of such a system and also to get buy in from the population of the informal settlement. However, some residents may still not provide such information, causing the system to fail in some areas.

Another issue which may be contentious is taking photos of the informal settlement buildings which would allow for planning departments and operators to see the type of buildings at a particular point. This may possibly be used to provide landmarks to fieldworkers when responding to calls. A similar approach to the previous case may be presented, but the lack of acceptance by the population may prevent the availability of such features.

These shortcomings should not dilute the value of the GISFIS system, as the system still provides other information which is valuable to municipalities. However, the lack of such information from databases may pose additional strain on the system resulting in errors. It is therefore necessary that developers consider these issues in the development of GISFIS systems. Municipalities should also incorporate tests into their verification activities to ensure that the systems developed do not fail due to the lack of information.

The integration of GISFIS into other systems may furthermore pose as a challenge to developers as they will not have access to those systems and may have little information to work with when trying to do the integration. The municipalities may need to involve the service providers responsible for maintaining those systems and coordinate the integration. The specifications around this integration will need to be developed separately to ensure that all systems are able to communicate with each other in a transparent manner.

Another challenge may be the requirement to use 3D-mapping tools such as Google's Project Tango and the integration of such information into GISFIS systems, as well as the integration of the hardware required into a data capture device developed specifically for GISFIS. Concession is made in the GISSIS for the use of smartphones as a data collection device. The term 'smartphones' may be interpreted broadly to include tablet devices and as such may allow for the use of Google's Project Tango tablet which is a device that includes all the required hardware to make use of the 3D-mapping tool. Whilst the use of such a tool may be seen as over-design, the benefit of using such a device has great potential in the development of GIS tools for informal settlements. In the development of the GISSIS, the author saw an opportunity and considered the role Google may possibly play in the implementation of Project Tango to a GISFIS as it is for the development of communities, which may appeal to Google's corporate social responsibility programme. The author also proposes to present the idea along with this dissertation and the GISSIS to Google's Project Tango team post completion of the research.

6.2 Conclusion

Through the research conducted during the course of this dissertation, it has been exciting to note the role technology plays in protecting humanity from disasters and the efforts that people have made to assist others, especially the less privileged. It has been disheartening to learn about the number of disasters and the lives that have been lost in South Africa's informal settlements due to the inability of emergency services to respond speedily to such disasters and due to the conditions in these settlements. The GISFIS is envisaged to change the way emergency service teams work by allowing them to conduct emergency response exercises based on simulations and consequently enable them to respond faster in real emergencies.

The development of the GISSIS is seen as a step toward the development and upliftment of informal settlements. Whilst it does not provide any additional information to municipalities yet, the author is hopeful that having a specification in place for such a system will pave the way for its development.

The GISSIS may not be as comprehensive a specification as required by the problem statement and is subject to be updated as new technologies are developed and as the needs within informal settlements change. The specification may also be updated based on the specific needs of municipalities. The revised specifications will supersede the basic specification developed as part of this research.

Although the study was based on Sicelo, which is small relative to the sprawling informal settlements seen towards the major cities in the country, the results of the study can be applied to any informal settlement wherever it may exist. The full benefit of this study will not be realised unless the tool is actually developed and rolled out to the much larger, sprawling informal settlements which exist in South Africa and possibly, across the world.

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APPENDIX A – GEOGRAPHICAL INFORMATION SYSTEM SPECIFICATION FOR INFORMAL SETTLEMENTS (GISSIS)

North West University

System Design Specification

Geographical Information System Specification for Informal Settlements (GISSIS)

June 2015

Preface

This specification is specifically for GIS systems developed for informal settlements and provides the minimum system requirements for such a system. Where sections of this specification are not currently required for a specific project, the municipality shall explicitly state which sections are not currently applicable. The system developer shall however make provision in the development of the system for future inclusion of the excluded sections.

The municipality may at their discretion include additional requirements to this specification. Should there be any conflicting requirements, the developer shall request written clarification from the municipality.

Table of Contents

1. Abbreviations

B-BBEE – Broad-Based Black Economic Empowerment

GB – Gigabyte

GIS – Geographical Information System

GISFIS – Geographical Information System for Informal Settlements

GISSIS – Geographical Information System Specification for Informal Settlements

GUI – Graphical User Interface

IT – Information Technology

MP – Megapixel

RAM – Random Access Memory

RDP – Reconstruction and Development Programme

SDS – System Design Specification

SIM – Subscriber Identity Module

SRS – System Requirement Specification

SQL – Structured Query Language

UPS – Uninterruptable Power Supply

VPN – Virtual Private Network

2. System Definition

2.1. Purpose

a. The purpose of this specification is to define the requirements for a system which shall be used to manage the development of informal settlements.
b. The system shall provide features that allow improved emergency response to disaster situations within informal settlements.
c. The system shall contain geospatial information which includes, but is not limited to, the coordinates of the informal settlements and all routes and structures within it.
d. The system shall provide simulation functions which are defined in this document.
e. The system shall be developed using this document as a baseline and shall adhere to every specification within this document unless authorised to deviate with a valid, documented and signed-off reasoning and agreement.

2.2. Scope

a. This document outlines the system requirements for the Geographical Information System for informal settlements (GISFIS).
b. The design of the Geographical Information System for Informal Settlements (GISFIS) shall follow the technical, functional and performance requirements that are detailed in this document.
c. The infrastructure supporting the GISFIS, as well as maintenance and training requirements, shall adhere to the requirements in this document.

2.3. Applicability

a. The Geographical Information System Specification for Informal Settlements (GISSIS) is applicable to the design and implementation of any GIS that is to be applied and deployed in informal settlements within South Africa.
b. This document makes reference to external systems. The GISSIS does not apply to the development of external systems – where reference is made to such systems, only the interface requirements for the GISFIS are defined within this document.
c. The GISSIS may also be expanded based on the end users' special requirements. Such additional requirements shall form an addendum to this document.
d. Where there is a discrepancy between any other document and the GISSIS, the GISSIS takes precedence.
e. The GISSIS may refer to subsystems that require further specifications to be developed. Should the system being developed require such subsystems, those specifications shall be developed prior to the design being initiated.

2.4. Applicable documents

The documents that feed into this System Design Specification (SDS) are:

a. System Requirement Specification (SRS) for a GISFIS
b. Dissertation: 'Development of a geospatial information system specification for informal settlements'.

3. System Overview

3.1. General

a. The GISFIS shall be an integrated hardware and software solution that collects and provides geographical information on informal settlements to the end user.
b. The GISFIS shall contain population data related to the geographical information.
c. The geographical information as well as the population information shall be stored in databases.
d. The data shall be stored in a format that allows data to be manipulated by the system.
e. The data shall be queried using Structured Query Language (SQL).
f. The GISFIS collects data by means of a portable 'field device' which shall be developed specifically for the purpose.
g. The GISFIS shall be developed with the protection of information being prioritised to ensure no misuse of population data.
h. The GISFIS shall be standardised as far as reasonably possible to allow for replication to other informal settlements in other municipalities, without having to redevelop GISFIS for another area.
i. The GISFIS shall be developed to accommodate the transition of informal settlements to formalised housing.
j. All formal housing which is located within informal settlements shall be included in GISFIS.
k. Data in GISFIS on informal settlements that have been transitioned to formal housing shall be exportable to the municipality's existing GIS for formal areas.

3.1.1. Disaster scenario simulation

a. The GISFIS system shall have a disaster scenario simulation plugin module.
b. The disaster simulation system shall include the following scenarios:

i. Fire

The fire simulation shall allow a user to indicate the source of the fire, materials surrounding the source of the fire and weather conditions. Based on these inputs the spread of the fire shall be simulated.

The program shall respond to simulated firefighting measures such as water sprays, fire breaks and other firefighting methods.

ii. Floods

The flood simulation shall indicate the flow of water based on user inputs which may be rain, a burst water pipe, broken dam wall , etc. The program shall consider the topography of the land when simulating flow. The simulation shall take into account fixed and moveable structures including informal structures.

iii. Medical Emergency

The simulation shall calculate the expected response time for an emergency vehicle to reach the scene of the medical emergency. The user shall input the type of vehicle available and weather conditions. The simulation shall take into consideration the width of the vehicle and choose appropriate routes accordingly.

iv. Gale force winds

The user shall provide a wind direction and speed. Considering structures in the path of the wind and the topography of the informal settlement, the direction of flying objects can then be simulated.

v. Community unrest / riots

The simulation shall output police response times for such events based on the location of the unrest and the size of the protesting crowds.

c. The disaster scenario simulation shall allow future development of unforeseen scenarios or scenarios specific to a particular area.

3.1.2. Subsystems

a. The GISFIS system shall comprise of various subsystems (discussed in 3.3) which work concurrently to enable proper utilisation of GISFIS.
b. These subsystems shall be interdependent and are fundamental to ensure correct operation of GISFIS.
c. The various subsystems of GISFIS shall be contained on a server with clients pulling information as required.
d. The GISFIS system with all of its subsystems shall be deployed across the municipality simultaneously, with concurrent training for all users of GISFIS.
e. The servers shall not be utilised by users for interacting with GISFIS. Users shall only interact with GISFIS using client devices or field devices.

3.2. GISFIS system capability

a. The GISFIS shall be designed to collect geographical and population data for an entire informal settlement.
b. The GISFIS system shall handle multiple informal settlements per area/municipality.
c. The GISFIS system shall be designed to handle a population of at least 20 000 people per informal settlement.
d. The GISFIS shall be designed to allow at least 50 users to access the system simultaneously on a local network, without overloading the network infrastructure or the server.
e. The GISFIS system shall reside on the existing municipal network.
f. The GISFIS client software shall be compatible with standard issue IT (Information Technology) hardware (laptops/desktop PCs) for basic interactions.
g. The GISFIS system shall be developed in a way that allows modules to be added on in future whilst the system is running.
h. The GISFIS system shall integrate with existing GIS systems and other population databases.
i. The GISFIS system shall pass data to third-party software using SQL queries.
j. The GISFIS shall query other databases using SQL.
k. The GISFIS system shall allow for the addition of early warning systems to GISFIS which alert emergency response teams to a potential emergency.

3.3. GISFIS system breakdown

The GISFIS is defined by the following subsystems:

a. Hardware
    i. Field device hardware
    ii. Smartphones
b. Software

i. Databases
ii. Server software
   - GIS
   - Population database
   - Dwellings
   - Emergency response
   - Disaster simulation
   - Planning
   - Error reporting
iii. Client software
   - Transacting with GIS, population database, dwelling types, emergency response, disaster simulation and planning.
   - Reporting
     - Reporting of data
     - Reporting of errors
iv. Smartphone software
   - Capturing of geographical information, dwelling types and population data.
v. Field device software
   - Capturing of geographical information, dwelling types and population data.

c. Training
   i. Training of fieldworkers on data capturing
   ii. Training of planning teams on how to use planning and simulation
   iii. Training of emergency response teams on using the system for emergencies
   iv. Training of emergency personnel on disaster simulations

d. Maintenance
   i. Support of field hardware
   ii. Support of IT infrastructure to be incorporated into the IT department

e. Education
   i. Education of informal settlement communities on the benefits of using the system

4. Functional requirements

4.1. GISFIS general design requirements

a. The GISFIS system shall include all of the subsystems defined in 3.3.
b. The developer shall propose optional and value-adding features to the municipality prior to commencement of design.
c. The developer shall provide mock-ups of the Graphical User Interface (GUI) to the municipality for approval.
d. The developer shall consider ergonomics when designing the GUI.
e. The GUI shall follow the design cues of the operating system installed at the municipality.
f. The hardware and software shall be upgradeable at a server level and at a client level without the loss of any data or personal settings.

4.2. Software design

4.2.1. Database

a. The GISFIS system shall be a database-driven system.
b. All databases shall be sufficiently protected against unauthorised access.
c. Databases shall be protected from users trying to copy or move the database.
d. A separate database shall be developed for:
    i. Geographical information
    ii. Population information
    iii. Dwelling information
    iv. Emergency equipment
    v. Users
e. The databases shall contain one-to-one relational information linking the databases where required.
f. The databases may also contain one-to-many and/or many-to-many relationships.
g. The developer shall provide a detailed document outlining the following information at the minimum:
    i. Number of databases
    ii. Fields per database
    iii. Field types
    iv. Relationships between databases
    v. Unique identifiers
    vi. Access restrictions
h. All databases shall be SQL databases.

4.2.1.1. Geographical information database

a. This database shall contain the latitude and longitude coordinates describing the informal settlement
b. The database shall record the altitude per coordinate.
c. The database shall capture the altitude of each informal settlement.
d. The altitude of open areas shall be measured accurately (at multiple points, high points and low points) to ensure simulations work correctly.
e. Where the coordinates of an area type, for example “dwelling” or “open area”, need to be captured, only the perimeter of the area should be plotted using field devices and all coordinates within that perimeter shall be added as the correct area type.
f. Each record shall have an identifier to determine whether that record refers to a dwelling, an open area, gravel road, etc.

4.2.1.2. Population information database

a. This database shall contain the information of the population within the informal settlement.
b. Each person residing in the informal settlement shall be captured into this database.
c. Each person entered into the database shall have an ID number in their record.
d. Every person in the informal settlement is to be linked to a specific dwelling which will in turn be linked to a geographic coordinate.
e. A picture of the person in front of their dwelling shall be allowed for – this is optional.
f. The telephone number of each person should be recorded. If a person does not have a telephone number, the number of another person residing in the same dwelling or a dwelling nearest to theirs may be used.

g. Optional information may be requested by the municipality to maintain a record of the unemployed individuals so that the municipality may contact them should there be a job that suits their skills. This information may include:
    i. Sex
    ii. Race
    iii. Employment status
    iv. Skills
    v. Pictures
h. The information contained within GISFIS databases shall only be used for the purpose of GISFIS and shall not be sold or used for any other purposes.

4.2.1.3. Dwelling information database

a. This database shall be used to capture all physical and structural information regarding the dwelling.
b. Each dwelling shall be linked to a geographical coordinate
c. Each dwelling shall have a selectable field to identify the material used to build the dwelling. The options are:
    i. Brick
    ii. Steel
    iii. Wood
    iv. Rubber
    v. Plastic
    vi. Mud
    vii. Grass
    viii. Fibreglass
d. Administrators may modify the list above to add materials that are commonly used in an area.
e. The dwellings shall be linked to the people staying in them.
f. The manner in which the dwelling is built shall be captured – that is, whether the dwelling is well-built or not.

4.2.1.4. Emergency equipment database

a. This database shall be used to capture all emergency related equipment in the informal settlement.
b. Each piece of equipment shall be linked to a geographical coordinate.
c. Emergency equipment include, but is not limited to, water points, electricity supply points, ambulance meeting points and any other infrastructure that is of importance to the emergency response department.

4.2.1.5. Users database

a. This database is used for access to the GISFIS system and is not linked to any geographical information.
b. The database stores usernames and encrypted passwords for all GISFIS system users.
c. Each user is assigned an access level which restricts them to information they are authorised to see.
d. Users may be assigned to multiple user groups.
e. Based on the access group a user belongs to, they may be allowed to either create, modify or delete records from the database.
f. Only users with privileged access may delete data from the database to protect the integrity of the system.

g. The GISFIS system contains sensitive data about the population. Only authorised persons may view this data and a separate access level is to be created accordingly. Users who do not belong to this access group may only view filtered data that does not contain sensitive information.
h. The type of data that may be deemed sensitive includes, but is not limited to:
   i. Identity numbers
   ii. Telephone numbers
   iii. Pictures
   iv. Sex
   v. Race
i. The municipality shall be consulted prior to development to verify the type of data that shall be classified as sensitive.
j. A user group shall be developed to allow view-only data which excludes sensitive information but allows the user to navigate data that is not sensitive.
k. Certain users may be allowed to search for individuals within the GISFIS or the RDP database, using a person's ID number.

4.2.1.6. Emergency log

a. The emergency-log database shall be used to capture details from incoming emergency calls.
b. The emergency log shall keep a record open until the emergency call is closed.
c. The emergency log shall record details including:
   - the type of incident;
   - location of the incident;
   - caller details;
   - time of incident;
   - injuries or deaths – with distinction between adults and children;
   - whether it was an actual emergency;
   - time of arrival of emergency personnel, and
   - additional notes.
d. Reports from the emergency log shall include most common incidents and times of such incidents, to allow for effective planning to prevent such incidents.

4.2.2. Server software

The software developed for the server shall allow for all of the following capabilities of the GISFIS system:

a. Storing of data in databases as per the database design
b. Retrieving of data from databases
c. Reporting on data within the databases
d. The server software shall allow for the use of data from the open-source Project Tango which allows for 3D scanning of objects. The field device shall have 3D-scanning capabilities as per Project Tango or similar and shall be used to capture 3D data of the informal settlements.
e. The emergency response software shall allow emergency response personnel to provide details to fieldworkers regarding locations of emergencies and surrounding emergency infrastructure.
f. The planning software shall allow the planning department to identify areas that require immediate attention
g. The planning software shall identify suitable areas for building RDP homes, based on input requirements.

h. The planning software shall identify suitable and available pieces of land for future emergency housing and to ensure that new informal settlements are not developed in these areas.
i. The GISFIS software shall allow for collaboration between departments – specifically the planning and emergency response departments.
j. The GISFIS software shall allow for the monitoring of remote devices, including the mapping of device locations for viewing, tracking and tracing.
k. The software shall allow for the authorisation/de-authorisation of remote devices to access the GISFIS server.
l. The GISFIS software shall allow for the simulation of disaster scenarios such as uncontrolled fires, floods, heavy winds, heavy rains and disasters specific to the region.
m. The simulation shall be a graphical simulation with a minimum 2D drawing.
n. The simulation shall be overlaid as a layer onto a map of the informal settlement.
o. A high resolution image of the informal settlement shall be overlaid onto the map as a layer.
p. The GISFIS software shall provide navigation routes for emergency personnel to follow in response to a disaster within informal settlements. The software shall cater for vehicle-type route restrictions to ensure emergency vehicles are able to reach their destination without having to re-route.
q. Emergency personnel shall be able to update the GISFIS based on feedback they receive from emergency response personnel in the field. These updates shall be submitted to the planning department for approval.
r. The server shall have a built-in web server to allow clients to interact with GISFIS without the need for a desktop application.
s. The server shall link identifying landmarks to GPS coordinates to allow for triangulation of caller locations to enable emergency services to respond faster to calls.
t. The system shall incorporate change-management principles to allow users to report or correct errors in a manner that can be traced to a specific user. The changes made to geographical data are to go through a review and approval process.
u. The system shall allow for version control on the database and the server software.
v. The software shall identify areas where emergency infrastructure is lacking so that the deployment of the appropriate infrastructure may be prioritised.

4.2.3. Client software

a. The clients shall access the server using a web interface to access the GISFIS web server.
b. The web server shall allow for a global login (i.e. using a user's Windows login details to login to GISFIS).
c. The web server shall allow clients using Internet Explorer, Microsoft Edge, Google Chrome or Mozilla Firefox browsers to access GISFIS content.

4.2.4. Field device software

a. The field device shall make use of the open-source Project Tango software to allow for 3D scanning.
b. The field device shall operate on the Android operating system.
c. The field device shall always maintain the latest available version of the Android operating system.
d. The field device shall be updated when it is in its charging cradle within six months after the latest version of the operating system is released by the operating system vendor, to ensure that any malicious bug-fixes included in the software update is installed.
e. The Android version on the field device shall have the browser disabled.
f. The Android version shall have all app-stores disabled.

g. The device shall be preloaded with the Android version containing the GISFIS application on it.
h. The device shall synchronise the data collected from the field whilst the device is in its charging cradle, using the municipality's Wi-Fi network.
i. The device shall not allow the installation of applications from unknown sources.
j. The device shall connect to the municipality's network through a VPN.
k. The file manager shall be disabled on the field device.
l. The fingerprint scanner shall be activated the method of unlocking the screen in order for the application to work.
m. The device shall report its exact location to the GISFIS server at all times.
n. In the event that the device is lost or stolen, a remote wipe shall remove all data that can compromise the GISFIS system, or which may provide population information.
o. After a wipe is performed, the device shall continuously update its location to the GISFIS server to allow the tracking and recovery of the device..
p. Every device needs to be authorised on the GISFIS server before it may add, modify or remove data.

4.2.5. Smartphone software

a. Whilst smartphones shall be supported, it shall not be the preferred method used for field-data capturing and shall only be used when there is a specific need for additional data-capturing methods.
b. All smartphones used for GISFIS shall use the Android operating system running V4.1 or later.
c. The design of the application shall conform to Android design guidelines.
d. The user interface shall follow the interface guidelines recommended by the operating system provider to ensure that the user is familiar with the interface of the new application.
e. The application shall only be installed on a municipality-issued phone, not on a private phone.
f. Where a personal phone has a work mode the application may be installed on a work profile
g. The device shall allow the GISFIS server or the municipality's email server to be a device administrator to allow remote wiping of the device.
h. The device shall connect to the municipality's network through a VPN.
i. The file manager shall be disabled on the field device.
j. The fingerprint scanner shall be used to unlock the screen in order for the application to work.
k. All devices need to be authorised on the GISFIS server prior to access being granted to add, modify or remove data.
l. The device shall report its location to the GISFIS server at all times.
m. If the device is a personal phone, the lost or stolen phone shall be wiped of all data and it would be the owner's responsibility to report the missing device to the authorities.
n. In the event that a municipality-issued device is lost or stolen, it shall be tracked using Android Device Manager or the updated equivalent to allow the recovery of the device.

4.3. Hardware design

This section describes the GISFIS hardware requirements. The network architecture and other hardware requirements are discussed. The GISFIS system shall allow for two types of field devices; smartphones and a specifically designed field device. Whilst smartphones shall be supported, it shall not be the preferred method used for field-data capture and shall only be used when there is a specific need for additional data-capturing methods.

4.3.1. Network architecture

a. The network architecture of the GISFIS system shall be a star architecture.
b. The server shall sit on the existing municipal network with a firewall between the GISFIS server and the municipal network.
c. The GISFIS clients are standard issue computers and shall access the GISFIS server through the firewall.
d. The firewall shall be configured to allow access to the GISFIS clients only.
e. A separate firewall shall be installed between the GISFIS server and an internet connection. This firewall shall be configured to allow appropriate access from authorised smartphones and field devices.
f. The connection to the GISFIS server shall be through a VPN between the field devices/smartphones and the GISFIS firewall.
g. There shall be a redundant internet connection for the GISFIS servers as the GISFIS servers are used for emergency response.
h. The redundancy of the internet connection shall be by means of at least two of the following technologies:
    - Either one of the following:
        i. ADSL
        ii. VDSL
    - And one of the following:
        i. Wireless (such as iBurst or similar - Not Wi-Fi)
        ii. 3G, HSDPA, HSDPA+ or LTE

i. The modems used for internet connection shall have a UPS supply with a minimum 8hour battery backup.
j. All server hardware and client stations used for emergency response shall have a redundant-network interface card.

4.3.2. Servers

a. The servers used for GISFIS shall be rack-mounted servers
b. There shall be a redundant server to ensure that in the event of a hardware failure, all the data is backed-up onto the redundant server.
c. The server shall make use of appropriate server motherboards, processors, RAM, hard drives and power supplies.
d. The servers shall have a redundant power supply with the primary being the grid supply.
e. The servers shall be powered from a UPS supply with a minimum 8-hour battery backup.
f. There shall be a separate UPS supply for each server.

4.3.3. Clients

a. Standard municipal-issued computers may be used as GISFIS clients.
b. Where a client is being used as an emergency response station, the following shall apply:
    i. The client shall have a UPS supply with an 8-hour battery backup.
    ii. The client shall have a redundant internet connection (i.e. the LAN connection and one other internet connection).
    iii. The client shall have a redundant power supply.

4.3.4. Smartphone hardware

a. Where smartphones are used, the hardware of the smartphone shall support:
    i. GPS

ii. Wi-Fi
iii. 3G data connection
iv. A touchscreen (minimum 5”)
v. At least 2GBgb RAM
vi. 5MP Camera
vii. Fingerprint scanner

4.3.5. Field device hardware

a. The GISFIS field device shall be developed specifically for GISFIS.
b. The GISFIS device shall make use of the open-source Project Tango technology available or similar technology.
c. The device shall have the following minimum hardware requirements:
    i. GPS
    ii. Wi-Fi
    iii. 3G data connection
    iv. A touchscreen (minimum 7”)
    v. At least 2GB RAM
    vi. 3MP Camera
    vii. 3D depth sensor to allow for 3D scanning
    viii. Fingerprint scanner
d. The device shall have a capacitive display.
e. The device shall have a stylus incorporated into the shell.
f. The device shall be developed for use in rugged environments (e.g. it shall be shock resistant).
g. The device shall have a removable battery.
h. The device shall have a minimum ingress protection rating of 67 (IP67).
i. The device shall have a built-in SIM card with access to data only.
j. The charging/connectivity interface shall make use of a USB Type-C interface.
k. A battery charging cradle shall be developed to charge a field device along with one spare battery.
l. The position of the battery charging connector shall be centralised at the base of the field device and the battery charging cradle.
m. The battery charging cradle shall allow for devices of varying width (4mm variation) and thickness (2mm variation).
n. The battery life of the field device shall allow for 12hours continuous use at maximum brightness.

5. System interfaces

a. The GISFIS shall allow importing and exporting of data to existing GIS systems used by the municipality.
b. The data from other GIS systems shall be imported transparently to GISFIS.
c. The data shall be accessed live from other systems.
d. The data from GISFIS may be queried live from other systems.
e. The importing integration shall be done by the GISFIS vendor.
f. The GISFIS vendor shall collaborate with the existing GIS systems vendor to ensure that the data is imported correctly.
g. Security for access from other systems shall be applied based on the requirements listed in 4.2.1.5.

6. System operations

6.1. Maintenance

a. The developer shall identify all maintenance requirements for the GISFIS.
b. The developer shall develop a maintenance plan to be approved by the municipality.
c. The developer shall provide a minimum 3-year guarantee on the service agreement and a minimum 5-year warranty on all hardware.
d. The developer shall provide a guarantee that the software is bug-free and a 12-month warranty on all software.
e. All maintenance activities shall be vendor agnostic and may be contracted to third parties.
f. Maintenance of the GISFIS system shall be managed by the municipality's IT department.

6.1.1. Reliability

a. The system availability shall be 99.9% as it is crucial for emergency response.

6.1.2. Spare parts list

a. The developer shall provide a list of all spares required for the upkeep of the system.
b. One spare battery with a minimum 5-year shelf life shall be provided for each field device.
c. Spare batteries for field devices and UPS shall be off-the-shelf purchases and not unique to the GISFIS system.
d. Batteries for field devices shall follow the design of off-the-shelf batteries of popular smartphones to allow for the use of smartphone batteries with the field device.

6.2. Personnel and training

a. Training shall be provided by the system developer to the following personnel:
    i. System administrators
    ii. Planning administrators
    iii. Planning team
    iv. Emergency response administrators
    v. Emergency response team
    vi. Fieldworkers
b. The system developer shall provide a comprehensive user manual for the server and client software.
c. The system developer shall develop a comprehensive user manual for both the field device and mobile application used to capture data.
d. The system developer shall provide a training manual separate to the user manual to allow the end users to be trained on the entire system in a controlled manner.
e. The requirements for training shall be developed further as part of future work.

7. Environmental conditions

a. The system shall be designed for use in varied conditions as informal settlements are located in various geographical areas with different climatic conditions.
b. GISFIS client and server stations shall be located in environmentally protected and controlled areas with temperatures ranging from 0° Celsius to 45° Celsius.

c. GISFIS field devices (excluding smartphones) shall operate in areas ranging from -5° Celsius to 45° Celsius.
d. GISFIS field devices shall have an adequate IP rating as described in hardware specific requirements.

8. System security

8.1. Protection of information

a. The GISFIS system contains sensitive and personal data which shall be protected
b. The data contained within GISFIS shall be encrypted and password protected.
c. Users shall not access GISFIS without a username and password.
d. Only users authorised by the municipal manager or by somebody delegated by him shall access GISFIS.
a Users shall only have access to data and parts of GISFIS that are in their field of duties (for example, the planning department may not access data meant for emergency personnel only).
e. The municipality shall maintain a register of all users, their positions and access levels.
f. The access register shall be reviewed every quarter to ensure that the user-access list remains relevant.
g. All users need to sign in at least once a month from a local (internal) network to maintain access to GISFIS.

9. Information management

a. All IT requirements shall follow the requirements of the municipality's IT department.
b. The system developer shall procure all server hardware required for the GISFIS.
c. All IT hardware purchased shall carry a minimum 3-year warranty.
d. The IT policies of the municipality shall be adhered to. Where the requirements of GISFIS conflict with such policies, the system developer shall bring the deviations to the attention of the municipality's IT department for concession.
e. Incremental backups of server data shall be made on a weekly basis. The backup data is to be stored in an off-site safe.
f. All hardware that is no longer covered by a warranty shall be replaced within three months of the warranty's expiry date.
g. The system developer shall provide telephonic support for a period of one year.

10. Documentation

a. The following documentation is required for the GISFIS system:
   i. Selection of hardware
   ii. Software design philosophy
   iii. Open-source software requirements
   iv. Software interfaces
   v. Commented software code
   vi. GISFIS process flow chart
   vii. Detailed software description
   viii. Equipment guarantees
   ix. Recommended spares
   x. Maintenance manuals
   xi. User interface requirements

xii. User interface graphics
xiii. Software installed
xiv. Software block diagram

10.1. Reporting

a. The requirements for reports from GISFIS is to be developed in future.

11. Sustainability

a. The GISFIS shall be developed to ensure the sustainability of the community in which it is implemented.
b. The GISFIS shall have the capability to log serious infrastructural and environmental concerns that affect or pose a threat to the community's safety to allow planning departments to prioritise such issues.
c. The municipality shall engage with communities to educate them about GISFIS prior to the deployment of GISFIS.
d. The municipality shall demonstrate the functionality of GISFIS to the local community prior to the deployment of GISFIS.

11.1. Job creation

a. GISFIS shall be developed locally to support local job creation and sustainability.
b. Municipalities shall train and employ people from within the informal settlement to capture the data required for GISFIS to create jobs within the community.
c. All hardware must be manufactured locally.
d. Municipalities shall invest in GISFIS by utilising and improving the system to ensure that GISFIS can assist in improving living conditions within South Africa which shall lead to the creation of additional jobs should the technology be used by other municipalities or be exported to other countries.
e. Improved local infrastructure shall enhance manufacturing and operation capability.
f. The development of GISFIS shall support and promote local IT and engineering skills development.
g. The developer shall use the development of the system as a training platform in hardware and software development for a suitable candidate from the informal settlement.

12. GISFIS life cycle

a. The system shall be designed considering the entire life cycle of the GISFIS.
b. The GISFIS life cycle is described as follows:
   i. Concept – The stakeholder and system requirements are defined and the possible solutions proposed. The conceptual phase is considered complete and the outcome of the concept phase is this document.
   ii. Development – The GISFIS system is developed by a system developer adhering to the requirements defined in this document. During this stage the system is tested and refined with input from the end user.
   iii. Implementation and Training – The system is deployed into the municipality and the personnel are trained on the field devices and the software system to ensure that they use the GISFIS as per its design-intent.
   iv. Utilisation – During this phase the GISFIS is used as per its design intent, including making use of simulation and utilising the system in real-time emergency response.

v. Support – Standby assistance shall be provided to the end users to ensure that the system runs smoothly with minimal downtime.

vi. Export – At this stage the informal settlement has been developed to a level at which the data can be exported to other GIS systems so that the GISFIS may be retired from operation.

13. Procurement

13.1. System developer requirements

To ensure the GISFIS is developed as per specification and performs as required, the system developers shall adhere to the following requirements:

a. The developers shall comply with all the requirements as prescribed in this document as well as any applicable laws (that may or may not be covered in this document) that are applicable to the field they operate in.

b. Where any work is subcontracted to other developers, the subcontracted developers shall comply with all the requirements stipulated in this document including those requirements imposed on the main developer.

c. The developers shall provide a document outlining their commitment to job creation within informal settlements and provide proof of such undertakings.

d. The developer shall be B-BBEE compliant.

e. The hardware that shall be procured shall be from local suppliers as far as reasonably possible.

f. The developer shall allow for continuous interaction with the municipality throughout the development of GISFIS.

g. The developer is to submit a programme for approval prior to any work commencing.

h. The programme shall outline all target dates and highlight important dates such as design-freezes.

i. The developer shall be held responsible for all items that are non-compliant with GISSIS and shall be responsible for resolving non-compliances prior to final payment. The developer may not claim additional charges for the resolution of non-compliances.

j. The developer shall deliver weekly progress reports to the municipality.

k. Where the developer exceeds on the agreed timeline, the municipality shall hold the developer liable for damages.

l. The supplier of the server and client hardware (desktops and laptops) shall be subject to the requirements of the municipality’s IT department.

APPENDIX B - STAKEHOLDER REQUIREMENT SPECIFICATION (SRS)

Appendix B - Stakeholder Requirement Specification (SRS)

The stakeholders are defined as follows:

- The municipality emergency services department
- The municipality planning department
- The author of the dissertation "Development of a geospatial information system specification for informal settlements"

Each requirement was evaluated and it was determined whether it was valid or not. After each requirement is given, comments or the rationale behind the requirement is discussed.

1. The system design shall provide the local municipality with a tool to capture and display the geographical landscape of an informal settlement.

   This is the baseline requirement for a GIS tool – namely, to capture geospatial data and display the results. Due to the lack of geospatial information available on informal settlements, such a tool is required in order to improve service delivery to informal settlements.

2. The tool shall provide for collaboration between various departments of the municipality, such as the planning and emergency response departments.

   Since the tool will be used concurrently by various departments within the municipality, collaboration between the departments is required. The relevant departments will be interdependent in the execution of the project and therefore collaboration is key to the success of the system.

3. The system shall be versatile, allowing for further development on various aspects at later stages.

   Municipalities may have different needs. Some may not have the funds to implement the entire system in one go. They may be able to make capital available over a period of time and so the development of the GISSIS may need to be staged (for example, add-on features like simulation can be added at a later stage once all data is captured correctly and verified).

4. The system shall allow for integration with third-party systems and databases.

   The municipality has existing databases that contain information about the population. The GISSIS should be able to use or give information to other programs to make the solution value-adding.

   Note: The third-party systems are to be defined. Generic third-party interfaces for all inputs/outputs from the system are to be provided. Third parties are to perform the integration by making the data available through the interface provided by the system developer.

5. The system shall be supported throughout its life cycle.

   Many vendors provide solutions but do not provide support to ensure that the system reach all the stages of its life cycle. By ensuring that the vendors are contractually bound to provide support, the municipality will enjoy the full benefit of GISSIS.

6. The system shall be easily expandable to incorporate new areas.

   There may be multiple informal settlements within a municipality and the system should allow for capturing an unlimited number of separate locations (independent of data and processing needs).

7. The system shall allow for data handling across multiple areas which includes, but is not limited to, searching across areas.

Based on previous arguments, the municipality may need to search for specific data across areas for example if they require land large enough for temporary shelter. The results need to be displayed and filtered accordingly.

8. The system shall be able to link into existing GIS systems for urban areas.

The municipality may need to overlay urban areas onto informal settlements for a better overview of their landscape.

9. The system shall be designed to be open source to enable future development by other parties.

In the event that the developer for any reason can no longer work on the development of the system, any other suitable contracted party should be able to continue the development for the municipality.

Note: Due to there not being sufficient vendors, it is highly unlikely that an open-source solution is possible. The developer is to provide an application programming interface (API) to allow third parties to link to their application.

10. Training on the system shall be provided.

Municipal personnel are not familiar with such a system and will need training in order to use the system effectively.

11. The system shall always be available due to it being required for emergency response at all times

The system shall be used to respond to emergencies. If the system is down, emergency response cannot be optimised and delayed response may exacerbate any emergency situations.

Note: Redundancy to be considered. Downtime less than 0.2%

12. The system shall be fast irrespective of the time of day or demand on the system

With multiple users doing various activities on the system, the network may be slow which may cause the system to be slow especially affecting emergency services.

Note: This is an emergency response requirement. The developer needs to consider network loading to ensure the system is not impacted due to an overloaded network.

13. Planning Requirements

13.1. The system shall be able to identify hotspot areas where the probability of informal settlement development is high.

Informal settlements can develop in open areas near or within urban areas, if those areas are not managed correctly. If the municipality is able to identify these locations, they may put measures in place to monitor these areas.

13.2. The system shall allow capturing of relevant population information.

The ultimate result is to eradicate informal settlements. Capturing population information within the informal settlements allows the municipality to link this data to the RDP housing list so that they may track the flow of people to formalised housing.

13.3. The system shall display population information during searches based on a user's access rights.

Due to the system holding confidential public information, access to data must be controlled. Only authorised personnel must have access to sensitive data.

13.4. The system shall include information from other available government databases.

All available relevant information must be utilised to gain maximum benefit from the system.

14. Emergency Services Requirements

14.1. The system shall include locations of all emergency infrastructure such as water points and electricity.

If the emergency services personnel are aware of the emergency infrastructure in the area it will allow them to respond faster and more efficiently to all emergencies.

14.2. The system shall highlight areas that lack sufficient infrastructure.

Municipalities must install such infrastructure in order to improve service delivery.

14.3. The system shall be designed to allow emergency services to identify a location based on information given to them by a caller.

Due to the lack of infrastructure it is difficult to locate the point of emergency. The solution should provide innovative ways to solve this.

14.4. The system shall provide routing information to emergency services, especially for areas with restricted access.

Roads in informal settlements are sometimes non-existent due to people building informal dwellings wherever there is space. At times, response vehicles cannot get to the location of the emergency due to accessibility issues.

14.5. The system shall provide a route based on the emergency vehicle type (ambulance/police/fire truck).

Some emergency vehicles will not be able to use routes with certain restrictions.

14.6. Emergency call centre agents shall have access to the system.

The system is designed to improve emergency services and it is therefore imperative that they have access to the system.

14.7. Emergency services should be able to report restricted access on routes using system channels, so that the relevant parties may update the system information or react to unplanned changes on the ground.

Since emergency services are using routes provided by the system, they may come across an obstruction which they will report to the central control room. They should be able to log the issue and submit it to the relevant department to correct the issue.

14.8. The system shall track emergency calls based on the type of event and shall routinely provide reports.

This will allow the municipality to determine the most common types of incidents in a certain area and will help improve planning and emergency services in that area.

14.9. The system shall highlight common emergencies over a period of time in reports and graphical formats.

This will assist emergency services to determine high risk issues in an area and help to plan and respond in a way as to prevent recurrence of such incidents.

14.10. The system shall allow for early-warning mechanisms to be developed and included as add-ons.

Emergency response can be improved through a proactive approach. Effective mechanisms to detect threats and emergency situations early on will mean emergency response is not solely reliant on people to report incidents.

14.11. The system shall allow for simulation packages to be installed as required.

This will allow municipalities to purchase a simulation package to suit their particular requirements.

14.12. Simulation packages are to be developed for various scenarios.

Based on the risks identified in an area, a specific simulation package is developed for that scenario.