Conditions for the diffusion of the Internet of Things in the healthcare sector of South Africa

Kgabo Seopa

A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Business Administration

Johannesburg, 2017

ABSTRACT

The Internet of Things (IoT) makes everyday devices the ultimate building blocks in the development of cyber-physical smart frameworks. The IoT has a variety of application domains such as healthcare. This IoT transformation is redesigning modern healthcare with promising technological, social, and economic prospects.

This study examines the conditions allowing for IoT to be diffused in the healthcare sector of South Africa. Using qualitative research techniques, the study identifies major conditions that constrain, and major conditions that favour its diffusion in South Africa. The study uses data collected through semi-structured interviews with representatives of 19 participants in the sector, including government institutions, private healthcare institutions, healthcare insurance organisations, vendors of IoT products and IoT service providers who provide IoT solutions in the South African healthcare market. The participants were identified using purposive sampling, and the data was analysed using thematic content analysis.

The study found that the diffusion of IoT in the healthcare sector of South Africa is constrained mainly by the healthcare regulatory environment. It is constrained also by lack of global standardisation and interoperability, lack of IoT networks, lack of cost effective IoT solutions, privacy and security vulnerabilities, the high cost of data, socio-economic factors, low level of entrepreneurial activities, lack of transition in the healthcare sector and lack of skills.

There are also several conditions that favour the diffusion of IoT in the healthcare sector. These include the proliferation of smart phones, availability of the Internet, accessibility and availability of the cloud infrastructure, and innovation in the healthcare sector.

The study concludes that, on balance, conditions allowing for the diffusion of IoT in healthcare are favourable. However, the pace at which it is diffused will depend on the extent to which the identified constraints can be overcome, and the factors that favour its development effectively exploited.

DECLARATION

I, Kgabo Jonas Seopa, declare that this research report is my own work except as indicated in the references and acknowledgements. It is submitted in partial fulfilment of the requirements for the degree of Master of Business Administration in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in this or any other university.

Kgabo Jonas Seopa

Signed at ……………………………………………………

On the …………………………….. day of ………………………… 2017

DEDICATION

To my children, Kgothatso, Phuti, and princess Naledi, who made many sacrifices and had to deal with a father who was not always there for the better part of two and half years. Without your support and understanding, I wouldn't have made it this far.

A special dedication to the extraordinary lady in my life, Kgaugelo, Mokwena moila lehlaka, moraka metsi a pula! Your assistance, encouragement and humanity is appreciated. Thanks for the journey well-travelled.

To my late father, Nare, who instilled in me the sense of independence from a young age. Tloga tloga e tloga kgale, modiša wa kgomo otšwa natso šokeng. Ke a leboga Mokone, Mokone wa ntšhi dikgolo, Mokone moila tlhantlhagane, Ngwana wa thaba ya magosi, Mokone moila nonyane e podudu, Matlala sekgoba dinaga tsabo makgolo' a' gwe Mokone.

To my special late mother, Seemole. Thanks for giving me the gift of life. We walked the education journey from the beginning. I was born poor, but I dared never to let you down. Although to the world you were my mother, to me you were the whole world. Even though your passing broke my heart into pieces, I forever cherish the everlasting memories we shared together. Robala ka kgotso Kolobe, Mathiba 'a ntsha phetole, la Mmatlopane 'a Monene, ke batho bago tsidibatsa nkwe ya mebala!

A special dedication to my special extended family, Kenny Seopa, Enny Mathiba and Aubrey Mantsho. You guys are stalwarts.

Thanks to all that have contributed to this journey, either directly or indirectly. A special thanks to Dr. Mmabo Moralo, Lucky Mashishi, Lerato Mautjane, Ledile Mphasha and Salaminah Moselane. Kea leboga!

ACKNOWLEDGEMENTS

Thanks to Hewlett Packard Enterprise for financial support and time off during examinations and attending electives. Thanks again for offering me fascinating and stimulating work opportunities which allowed me to practise a wealth of new skills I gained during this MBA.

Thanks to Dr. Diran Soumonni, my research supervisor. The research journey is daunting and yet interesting. Thanks for walking the path with me until the finish line.

Thanks to all the people who have spared me some time in their busy diaries to have a conversation about the Internet of Things - what a fascinating topic! I really appreciate your assistance and insights.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1 Purpose of the study

The purpose of this study is to examine the conditions that will allow the Internet of Things (IoT) to be diffused in the South African healthcare sector. The Internet of Things is the network of everyday devices inserted with sensors, actuators, electronics, software, and network connectivity that enable these objects to communicate and provide data that can be converted into useful information (Coetzee & Eksteen, 2011; Feki, Kawsar, Boussard, & Trappeniers, 2013; Ndubuaku & Okereafor, 2015; Wang, Yu, & Zhang, 2014; Xu, He, & Li, 2014).

1.2 Context of the study

At the core of IoT lies the Internet technology which is the fundamental enabler of IoT (Coetzee & Eksteen, 2011; Stankovic, 2014). The Internet is the global system of interconnected computer networks linking many devices worldwide using the Internet protocol communication suite (TCP/IP) (Schulte, 2013). It is a network of networks that consists of private, public, academic, business, government and other networks linked by a wide-ranging array of wired, electronic, wireless, and optical networking technologies (Friess & Vermesan, 2015; OECD, 2015a; Schulte, 2013; Tobergte & Curtis, 2013; Vermesan & Friess, 2014). The Internet transmits a wide range of information and services, such as the World Wide Web (WWW), electronic mail (e-mails), telephony, and file sharing through peer-to-peer networks (Behmann & Wu, 2015; Gilley, 2014; Schulte, 2013).

Coetzee and Eksteen (2011) believe that the Internet is a living entity which is continuously changing and evolving with new applications and businesses created continuously. However, in addition to an evolving Internet and associated applications, technology is also changing the landscape (Folk, Hurley, & Payne, 2015). Broadband connectivity is becoming affordable and universal (Coetzee & Eksteen, 2011; Okereafor, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010); devices / things have improved performance and became smaller with diverse on-board sensors (Andersson, 2015; GSM Association, 2014; Vermesan & Friess, 2014). This phenomenon has led to the proliferation of more devices becoming connected. That proliferation has in turn, led to a new paradigm: the Internet of Things (Behmann & Wu, 2015; Brody & Pureswaran, 2014; Coetzee & Eksteen, 2011; Sathi & Gayathri, 2016).

The Internet of Things also offers multiple opportunities that wellness promoters and hospitals can pursue, even as they optimise resources through automation of workflows, as well as process excellence (Carnaz & Nogueira, 2016; Sathi & Gayathri, 2016; Vujovic, Perisic, & Maksimovic, 2015). For instance, the study has found that the majority of hospitals use IoT for asset management (through asset tagging and tracking) and controlling humidity and temperature within operating rooms (Asia & Exclusive, 2015; Begum & Begum, 2017; Fischer, 2014; Govindarajan & Ramamurti, 2013).

The Internet of Things is defined by open standard organisations such as the International Telecommunication Union (ITU), European Research Cluster on IoT (IERC) and the Institute of Electrical and Electronics Engineers (IEEE) as a dynamic global network infrastructure with self-configuring capabilities based on standard and defined interoperable communication protocols where physical and virtual “things” have identities, physical attributes, communication capabilities and virtual personalities, and are seamlessly integrated into the data network (International Telecommunication Union, 2012; Minerva, Biru, & Rotondi, 2015; Vermesan et al., 2016). The Internet of Things is an area of interest for academics, businesses, entrepreneurs, inventors, investors, governments and society at large (Bien & Selvanathan, 2014; Lund, Morales, Turner, & MacGillivray, 2014; Ndubuaku & Okereafor, 2015; Xu et al., 2014).

The Internet of Things encompasses several trending technologies including cloud computing, big data, machine to machine (M2M) communication and sensors (Friess & Vermesan, 2015; Minerva et al., 2015; Vermesan et al., 2016). Globally, businesses are increasing their investment in IoT while the governments are also laying the infrastructure and policies to allow IoT to flourish (Wang et al., 2014). International Data Corporation (IDC), a market research firm, has predicted that by 2018, 60% of the top global 1000 companies will incorporate information technology and operational technology at the technology, process, security, and organisation levels to fully realise the value of their IoT investments (Macgillivray et al., 2016). IDC further predicts the worldwide market for IoT to grow at an average of 20% compound annual growth rate (CAGR) from USD1.9 trillion in 2013 to USD7.1 trillion in 2020, and this will be an immense contribution to the economy worldwide (Lund et al., 2014).

The Internet of Things is transforming the healthcare industry. This is done by redefining how devices, applications and people interact and interconnect with each other in providing healthcare solutions (Carnaz & Nogueira, 2016; Vujovic et al., 2015). The Internet of Things is constantly offering new tools and efficiencies that make up an integrated healthcare system (Islam, Kwak, Kabir, Hossain, & Kwak, 2015; Revathi, Vijani, & Vijanu, 2015; Vujovic et al., 2015). The intention of the integrated system created by IoT is to ensure that patients are cared for better, healthcare costs are reduced significantly and treatment outcomes are improved (Islam, Kwak, Kabir, Hossain, & Kwak, 2015; Revathi, Vijani, & Vijanu, 2015; Vujovic et al., 2015).

Because of the sensor devices, the healthcare applications using IoT are increasing day by day (Alex, Varghese, Jose, & Abraham, 2016; Hwang, Kim, & Rho, 2016; Yinbiao et al., 2014). The Internet of Things has provided development and growth to many medical applications including remote health monitoring, physical fitness programmes, Alzheimer's diseases, and elderly care (Jamalipour, Nikookar, & Ruggieri, 2016; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan et al., 2016).

In this study, diffusion of IoT in the healthcare sector refers to South Africa being able to harness the opportunity presented by the transition where IoT is not fully developed into wide implementation and use of IoT. This will be realised by the mass implementation and use of IoT in healthcare, thus, allowing South Africa to fully take advantage of and successfully diffuse IoT in healthcare. This diffusion of IoT will be measured by the progress made in the wide implementation of IoT in healthcare.

The benefits of IoT to the developing and emerging economies are substantial, and the developing and emerging markets like South Africa need a strategy to exploit this opportunity (Coetzee & Eksteen, 2011). If South Africa can harness the IoT opportunity, it could have an impact in the South African healthcare sector and therefore, the lives of its citizens. This is the context in which this study is based.

1.3 Problem statement

1.3.1 *Main problem*

The research study is to identify, extrapolate and evaluate the conditions which would allow IoT to be diffused in the healthcare sector of South Africa.

1.3.2 *Sub-problems*

The first sub-problem is to establish the main conditions, if any, that constrain the diffusion of IoT in the healthcare sector of South Africa.

The second sub-problem is to establish the main conditions, if any, that favour the diffusion of IoT in the healthcare sector of South Africa.

1.4 Significance of the study

The prospective benefits of IoT are limitless (Andrews, 2015; Coetzee & Eksteen, 2011; Lund et al., 2014; Manyika et al., 2015; Olsen, 2008; Wang et al., 2014). The Internet of Things applications are changing the way people live, work, learn and play by improving productivity, saving time, improving asset utilisation and opening new opportunities for economic growth, knowledge creation and innovation (Manyika et al., 2015; Wang et al., 2014). In essence, IoT improves efficiency (Bien & Selvanathan, 2014; Carnaz & Nogueira, 2016; Macgillivray et al., 2016).

The Internet of Things gives new functionality to private and public sector organisations by allowing them to develop new business models, optimise performance and manage assets (Friess & Vermesan, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014). The Internet of Things is an instrument used to interconnect things and act as an enabler of the hyper-connected society and as a result, it is expected that it will greatly contribute in addressing today's societal challenges, improve energy efficiency, support an ageing society and optimise all kinds of mobility and transport (Jamalipour, Nikookar, & Ruggieri, 2016; Vermesan et al., 2016).

The Internet of Things, globally, is a new phenomenon and research studies still believe that its potential is yet to be fully discovered (GSM Association, 2014; Rifkin, 2014; Vermesan & Friess, 2014). However, In South Africa, IoT is still under-researched (Coetzee & Eksteen, 2011; Miraz, Ali, Excell, & Picking, 2015; Xu et al., 2014). This study therefore, contributes to the knowledge base as there is limited information available about the impact of IoT in the healthcare of South Africa. Though there is collateral research regarding the conditions that have allowed other countries to advance in IoT, the study of the conditions which will allow IoT to progress in South Africa is limited (Coetzee & Eksteen, 2011; Miraz et al., 2015; Xu et al., 2014).

Today, the fields of the physical realm where we find "things" and the existing electronic structures have merged to form a connection between the various physical objects that help in the collection of data from various sources (Minerva et al., 2015; Miorandi, Sicari, De Pellegrini, & Chlamtac, 2012; Sathi & Gayathri, 2016). Though IoT has had a great impact on various fields like engineering, security, transportation through its strong interconnectivity, the most profound effect it has had has been on the healthcare system (Sathi & Gayathri, 2016). This impact ranges from the effectiveness of the ecosystem, healthcare prices, and availability of medicine across the world (Govindarajan & Ramamurti, 2013; Sathi & Gayathri, 2016). More often, in situations concerning the health of a person, medical needs arise unprecedented and there are many emergency situations which, through IoT, could be avoided or better managed (Alex et al., 2016; Revathi et al., 2015; Sathi & Gayathri, 2016). In these situations, IoT assists in measuring various body vital signs and spontaneously sends data to the data analysis centers for remedy (Sathi & Gayathri, 2016). The mobility of health-related information has also assisted researchers in making devices that allow patients to do home based care (Sathi & Gayathri, 2016).

The Internet of Things uses sensors connected to a microprocessor to gather and store data (Niewolny, 2013; Sathi & Gayathri, 2016; Vujovic et al., 2015). These data are then analysed to provide meaningful results to the interconnected output device. The Internet of Things is helping healthcare reach remote locations and ensures consistent monitoring of patients' vital signs (Niewolny, 2013; Sathi & Gayathri, 2016; Ovidiu Vermesan et al., 2016).

Some of the benefits of the diffusion of IoT in healthcare include:

Decreased costs: when healthcare providers use IoT healthcare solutions, patients' monitoring can be done on a real-time basis, thereby cutting down on visits by doctors (Alex et al., 2016; Govindarajan & Ramamurti, 2013; Manyika et al., 2015). Advanced homecare facilities will cut down on hospital stays and re-admissions (Behmann & Wu, 2015).

Improved outcomes of treatment: Through the interconnectivity of the healthcare solutions, caregivers now have the ability to access real time information. The real time information enables them to make informed timely decisions as well as offering evidence based treatment (Begum & Begum, 2017; Carnaz & Nogueira, 2016; Niewolny, 2013). This, in turn, ensures that healthcare provision is timely and treatment outcomes are improved, thereby improving people's lives (Asia & Exclusive, 2015; Vujovic et al., 2015).

Improved disease management: patients are monitored consistently and continuously, thereby enabling healthcare providers with the ability to access real time data (Carnaz & Nogueira, 2016; Hiremath, Yang, & Mankodiya, 2014; Niewolny, 2013). This creates the opportunity for diseases to be treated before they spread.

Reduced errors: the accurate collection of data, automated workflows and timely data driven decisions cuts down on waste, reduces system costs and minimises errors (Fischer, 2014; Fleisch, Weinberger, & Wortmann, 2014; Govindarajan & Ramamurti, 2013).

Improved patient experience: the interconnectivity of the healthcare systems through IoT, places emphasis on the needs of the patient (Begum & Begum, 2017; Hiremath et al., 2014). This provides proactive treatment, improved diagnosis accuracy, timely intervention by healthcare providers and enhanced treatment outcomes which result in an accountable care that is highly trusted (Begum & Begum, 2017; Hiremath et al., 2014).

Enhanced management of drugs: the creation of drugs and its associated management is a major expense in the healthcare (Carnaz & Nogueira, 2016; Revathi et al., 2015). Using IoT to automate and process leads to cost saving and better drugs management (Carnaz & Nogueira, 2016; Revathi et al., 2015).

This study may provide guidance to academics, entrepreneurs in IoT and healthcare, existing businesses that are already in healthcare or that want to expand into healthcare, investors who want to understand the opportunity presented by IoT for healthcare, inventors who will understand the IoT healthcare environment with its associated solutions requirements to develop chips, and government on how they can enable full IoT potential in healthcare to provide better healthcare to the South African population. According to Manyika et al. (2015) and Wang et al. (2014), for IoT to advance in the country, all participants need to play their role. A better understanding of the conditions which allow IoT to be diffused will enable all role players to understand how they can contribute.

As the study uncovers some of the conditions which allowed IoT to be diffused in other countries, this will in turn, benefit the healthcare sector, entrepreneurs, business organisations, investors, inventors and government in South Africa. The benefits will be on: what might be necessary for the government and health care sector to enable the environment by providing the appropriate policies and reforms to allow innovation, competition and wide adoption of IoT by both business and consumers locally and globally; for entrepreneurs and business organisations to tackle the opportunity and be internationally competitive; for investors to understand and appreciate the market landscape and size in South Africa. If successful, this will in turn, improve the economy and the lives of South African citizens. The study also contributes to the work of students and academics pursuing an expansion in the body of work on IoT in healthcare.

1.5 Delimitations of the study

The stakeholders included in the study include public healthcare centers (hospitals and clinics); private healthcare centers; organisations developing, selling and/or using IoT solution; government entities involved in healthcare; vendors who invent IoT healthcare products and solutions; and healthcare insurances. The common goal amongst all of these organisations is to automate some processes in healthcare using IoT technology to effect efficiency.

This study was only conducted in Gauteng Province, South Africa.

1.6 Definition of terms

The Internet of Things (IoT) – IoT is a network of physical objects (referred to as devices/things) which has, or can be enabled with an IP address for Internet connectivity which can then seamlessly communicate between objects and other Internet-enabled devices and systems (International Telecommunication Union, 2012; Minerva et al., 2015; Vermesan et al., 2016). In essence, IoT is the world where devices can communicate with each other or humans using a communication medium understood by both humans and devices to make meaningful contributions to the way humans live, work and play (Behmann & Wu, 2015; Rifkin, 2014b).

Diffusion of IoT - In this study, the diffusion of IoT is associated with the wide adoption of IoT and its associated healthcare solutions.

Healthcare center – in the context of this study, healthcare centres refer to hospitals and clinics. This healthcare centres are either public or private centres.

1.7 Assumptions

The following assumptions have been made regarding the study:

- The Internet of Things exists in South Africa; however, it is not yet diffused in the healthcare sector.
- The respondents are appropriately located within their respective institutions to provide the institutions' perspectives on the issues covered in the study. As such, respondents not familiar with the positions of their institutions would weaken the value of the information collected.
- The total number of respondents is sufficient to gain adequate data to form a coherent overview of the challenges facing IoT in the sector.
- All persons interviewed in the course of this study were assumed to be honest and forthright in their opinion and views. False data would have had a detrimental effect on the study's results.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This literature review covers some of the main conceptual issues that accompany the diffusion of IoT in healthcare, highlighting, gaps in knowledge and areas needing further research, if any. The literature review is structured such that the first part looks into IoT and its interrelationship with healthcare.

The literature further looks into the IoT technological framework and some of the services and applications offered by IoT in healthcare around the world. It further examines global developments in healthcare-based IoT.

Together with the potential the healthcare-based IoT has, the study further analyses the global IoT healthcare policies that have enabled the IoT in healthcare to be diffused.

The literature then considers an overview of the major global conditions that has allowed IoT in the healthcare to be diffused.

The literature concludes by examining the South African healthcare and IoT landscape.

2.2 Background discussion

Alex, Varghese, Jose, and Abraham (2016), Gapchup, Wani, Gapchup, and Jadhav (2016), and Revathi, Vijani, and Vijanu (2015) believe that IoT in healthcare is moving routine medical checks and other related healthcare services from the medical centres such as hospitals and clinics, to the home environment. These home environments provide easy care and access to medication to the patients, especially in case of emergencies. With home care, hospitals reduce the burden of looking after many patients and reduce their expenditure. They concluded that the patients benefit as they do not have to pay for each time they visit the doctor.

The possibilities and benefits of IoT in healthcare are endless. Below the study discusses what is healthcare, IoT and the possibilities they together bring to the healthcare sector.

2.3 The Internet of Things

The Internet of Things is a model where daily objects will have identifying, sensing, networking and processing capabilities (International Telecommunication Union, 2012; Minerva et al., 2015; Vermesan et al., 2016; Whitmore et al., 2015). These objects are meant to accomplish some objective by using these capabilities to communicate with one another (Behmann & Wu, 2015; Bien & Selvanathan, 2014; OECD, 2015a; Whitmore et al., 2015). Whitmoe et al. (2015) believe that ultimately, IoT devices will be universal, pervasive and context-aware, enabling ambient intelligence.

The term “Internet of Things” was propagated by the efforts of the Auto-ID Centre at the Massachusetts Institute of Technology (MIT) (Lopes Research, 2013; Sundmaeker, Guillemin, Friess, & Friess, 2010; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). In 2002, its co-founder and former head, Kevin Ashton, believed that there is a need for IoT which will be a standard way for computers to understand the real world (Ashton, 2009; Behmann & Wu, 2015; Sundmaeker, Guillemin, Friess, & Friess, 2010). Since then, many visionaries have galvanised the phrase the “Internet of Things” (Ndubuaku & Okereafor, 2015).

A couple of decades ago, the Internet began a process of being in a persistent state of evolution (Byung-Keun, 2005; GSM Association, 2014; OECD, 2015a). Initially, the Internet was distinguished by the World Wide Web (WWW), a network of linked HTML documents situated within Internet architecture, which gradually evolved into what is called Web 2.0 (Bien & Selvanathan, 2014; Coetzee & Eksteen, 2011; Friess & Vermesan, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). This Web 2.0, is where two-way communication became common which gave rise to user participation, collaboration and interaction (Bien & Selvanathan, 2014; Coetzee & Eksteen, 2011; Friess &

Vermesan, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). Technologies in Web 2.0 include social media, blogs, and some groups and organisations with collaborative web spaces that have become essential to modern social interaction and for global businesses as well (Whitmore et al., 2015). In the meantime, while Web 2.0 is currently dominating on the Internet, the technology industry has been working towards another goal, a new version commonly referred to as the Semantic Web, thus Web 3.0 (Bien & Selvanathan, 2014; Coetzee & Eksteen, 2011; Friess & Vermesan, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Whitmore et al., 2015).

The goal of this Semantic Web is to mark-up web content in a way that Artificial Intelligence (AI) is used, web content being understandable by machines, allowing machines and search engines to behave more intelligently (Whitmore et al., 2015). This standardised format would allow machines to process and share data independently without a need for human mediation (Bien & Selvanathan, 2014; Coetzee & Eksteen, 2011; Friess & Vermesan, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Whitmore et al., 2015).

While Internet technologies have been developing, technologies in Sensor Networks and Near Field Communication using RFID tags have also been gradually evolving (Ashton, 2009; Behmann & Wu, 2015; Whitmore et al., 2015; Xu et al., 2014). Now the combination of these two technologies i.e. Internet and Network Sensors is leading to a whole new world of possibilities and visions (Bien & Selvanathan, 2014; Manyika et al., 2015; Whitmore et al., 2015). Whitmore et al. (2015) believe that the prospect of a framework that would lead to direct devices (machine to machine (M2M)) communication over the Internet has led researchers to envision the benefits of bringing more devices online and allowing them to participate in the web as a vast network of autonomous, self-organising devices - this vision produced what is now referred to as IoT.

Though there is no universal definition for IoT yet, the core concept is that nowadays objects can be equipped with identifying, networking, sensing and processing capabilities that will allow communication with one another, with other devices and as well as services over the Internet to achieve some useful objectives (Friess & Vermesan, 2015; Senatore, 2010; Whitmore et al., 2015).

These concepts of IoT are not new, it has been years now that the technologies such as RFID and sensor networks have been used for tracking large-ticket items such as cranes and livestock in the industrial and manufacturing arenas (Friess & Vermesan, 2015; Lund et al., 2014; Whitmore et al., 2015). The direct M2M communication is also not new; it is basic to the idea of the Internet in which clients, servers and routers communicate with one another (Berg, Oiso, Sung, Paltridge, & Diaz-Pines, 2014; Gilley, 2014; Whitmore et al., 2015).

What IoT represents is an evolution of the use of existing technologies in terms of number and variety of devices across the Internet (Behmann & Wu, 2015; GSM Association, 2014; OECD, 2015a). For instance, most devices currently on the Internet were originally designed to be part of the Internet and have integrated processing, storage and network capabilities (Behmann & Wu, 2015; Friess & Vermesan, 2015; Whitmore et al., 2015). Devices such as servers, desktops, laptops, tablets and smart phones are some that are included (Behmann & Wu, 2015; Friess & Vermesan, 2015; Whitmore et al., 2015). IoT proposes to attach technology to everyday devices such as audio/video receivers, smoke detectors, home appliances, etc. and put them online even when initially they were not designed with such capability in anticipation (International Telecommunication Union, 2012; Minerva et al., 2015; Vermesan et al., 2016).

The other major IoT evolutionary change is that of the integration of networks that contain these kinds of devices, making each device directly accessible through the Internet (Whitmore et al., 2015; Yinbiao et al., 2014). For example, RFID has been used for years to track products through certain parts of the supply chain (Jamalipour et al., 2016; Olsen et al., 2014; Vermesan & Friess, 2014). However, there was no means/ability of tracking the products once they left the manufacture’s shelf or retail outlet (Whitmore et al., 2015). Likewise, there was also the need for consumers to gain access to the lifecycle information of products they had purchased (Whitmore et al., 2015). So IoT promises to enable product traceability throughout the entire product lifecycle by giving each product a unique identifier and making its generated data available through the network (Behmann, 2015; Vermesan & Friess, 2014; Xu et al., 2014).

Furthermore, IoT holds the promise of creating a global network supporting ubiquitous computing (Barcena & Wueest, 2015; Brody & Pureswaran, 2014; GSMA, 2015; Kerravala, 2014; Stankovic, 2014) and context-awareness among devices (Friess & Vermesan, 2015; Gilley, 2014; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Whitmore et al., 2015). Ubiquitous computing and context-awareness are key requirements of ambient intelligence, one of the key promises of IoT (Behmann & Wu, 2015; Friess & Vermesan, 2015; Miraz et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010).

Ambient intelligence would allow everyday objects to understand their environments, interact with people and make decisions (Behmann & Wu, 2015; Friess & Vermesan, 2015; Miraz et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). A world full of smart objects holds enormous promise for improving business processes and people's lives (Behmann & Wu, 2015; Bien & Selvanathan, 2014; Tapscott, 2014), however, it also comes with serious threats and technical challenges that must be overcome (Andrews, 2015; Barcena & Wueest, 2015; Folk et al., 2015). Some of these security challenges are discussed.

2.4 Technological framework

The diffusion of IoT in the application areas relies on several enabling technologies. Without these enabling technologies, it would be challenging to achieve the usability, interconnectivity and capabilities required for these applications in healthcare. Below, only core technologies to enable IoT in healthcare are discussed.

2.4.1 *Smart sensors*

The requirement to accurately measure, monitor and analyse a variety of health status indicators depend on the smart sensors (Behmann & Wu, 2015; Sreekanth & Nitha, 2016; Ovidiu Vermesan et al., 2016). These smart sensors combine a sensor and microcontroller, which enable it to harness the power of IoT in healthcare (Behmann & Wu, 2015; Friess & Vermesan, 2015; Revathi et al., 2015). The measurements can include basic vital signs such as blood pressure, heart rate, and as far deep as the levels of glucose or oxygen saturation in the blood (Begum & Begum, 2017; Gapchup et al., 2016; Takpor & Atayero, 2015). It is these smart sensors that are integrated into pill bottles and connected to the network to provide indication whether the patient has taken a dose of medication or not (Alex et al., 2016; Friess & Vermesan, 2015; Niranjana & Balamurugan, 2015). For these smart sensors to work effectively, the microprocessors are incorporated with several essential capabilities which are listed below (Friess & Vermesan, 2015; Manyika et al., 2015; Yinbiao et al., 2014).

Low-power operation

The devices are kept small with extended battery life at low cost.

Integrated precision-analog capabilities

This is to enable sensors to achieve high accuracy at a low cost.

Graphical user interfaces (GUIs)

The authors further said that this assists in improving usability by enabling display devices to deliver the information in detail. These GUIs also make it easy to access that information.

2.4.2 *Cloud computing*

Clouding computing offers IoT-based healthcare the facility for ubiquitous access to shared resources over the network (Carnaz & Nogueira, 2016; Jamalipour et al., 2016; Sathi & Gayathri, 2016). It also executes some operations to meet various computing needs. It is usually held in a centralised location where resources are shared (Carnaz & Nogueira, 2016; Jamalipour et al., 2016; Sathi & Gayathri, 2016).

2.4.3 *Grid computing*

Grid computing is cluster computing which is the backbone of cloud computing (Carnaz & Nogueira, 2016). The medical sensors do not have the capacity to perform some of the computational requirements. For that purpose, data is send to the cloud grid computing via the network for computing (Carnaz & Nogueira, 2016).

2.4.4 *Big data*

Big data is an enormous amount of data generated by diverse healthcare sensors (Behmann & Wu, 2015; Chen, Xu, Liu, Hu, & Wang, 2014; Friess & Vermesan, 2015). It provides tools for increasing efficiencies of relevant healthcare data and analytics. It assists in doing predictive analysis, telemedicine and advanced diagnosis.

2.4.5 *Networks*

Network is used for the sensors to communicate with the grid in the cloud (Behmann & Wu, 2015; Lopez Research, 2013; Yinbiao et al., 2014). These networks range from short range communication networks like Wireless Private Areas Networks (WPAN), Wireless Body Area Networks (WBAN), Wireless Local Area Networks (WLAN), IPv6 Low-power Wireless Personal Area Networks (6LoWPAN), and Wireless Sensor Networks (WSN), to long range communication network such as those used in cellular networks (Behmann & Wu, 2015; O Vermesan & Friess, 2014; Yinbiao et al., 2014). Other technologies used to design low-power medical sensors include ultra-wideband (UWB), BLE, NFC, and RFID (Friess & Vermesan, 2015; Hwang et al., 2016).

Characteristics such as low power consumption, low transceiver chip cost and large coverage area are the main building blocks of the low power wide area networks (LPWAN) technologies (Jamalipour et al., 2016; Petäjäjärvi, Mikhaylov, Hämäläinen, & Iinatti, 2016; Ovidiu Vermesan et al., 2016). In recent years, there has been a global rollout and prevalence of LoRaWAN, a LPWAN technology (Petäjäjärvi et al., 2016). The technology allows for the connectivity of the devices without the requirement for 3G or Wi-Fi (Petäjäjärvi et al., 2016). As it is an LPWAN technology, it also meets the requirements of low power usage for the connected devices.

2.4.6 *Ambient intelligence*

Ambient intelligence refers to the capacity of an IoT system to sense the environment and to respond to the presence of people and builds upon pervasive computing, ubiquitous computing, profiling, context awareness, and human-centric computer interaction design (Friess & Vermesan, 2015; Gapchup et al., 2016; Madakam, Ramaswamy, & Tripathi, 2015). Ambient intelligence allows for the continuous learning of human behaviour and executes any required action triggered by an event.

2.4.7 *Augmented reality*

Augmented reality enables users to see real-time, contextual information about their smart, connected products (Carnaz & Nogueira, 2016; Garcia-Macias, Alvarez-Lozano, Estrada, & Aviles Lopez, 2011; O Vermesan & Friess, 2014). As part of IoT, it plays a critical part in healthcare engineering on applications such as surgery and remote monitoring.

2.4.8 *Wearables*

Wearable devices are now at the heart of IoT in healthcare because of the full range of new capabilities pervasive connectivity brings. They assist in providing timely data regarding the patient (Behmann & Wu, 2015; Friess & Vermesan, 2015; Hiremath et al., 2014). It is through these wearable devices that we can gather crucial data about the vital signs of the patient. This data, through the network, is then sent to the grid enabled cloud. As part of the big data, it is analysed and the correct action is taken (Carnaz & Nogueira, 2016; Jamalipour et al., 2016).

2.5 The Internet of Things healthcare services

The Internet of Things is anticipated to enable a variety of healthcare services where each service will provide a set of healthcare solutions. Below major IoT healthcare services are discussed.

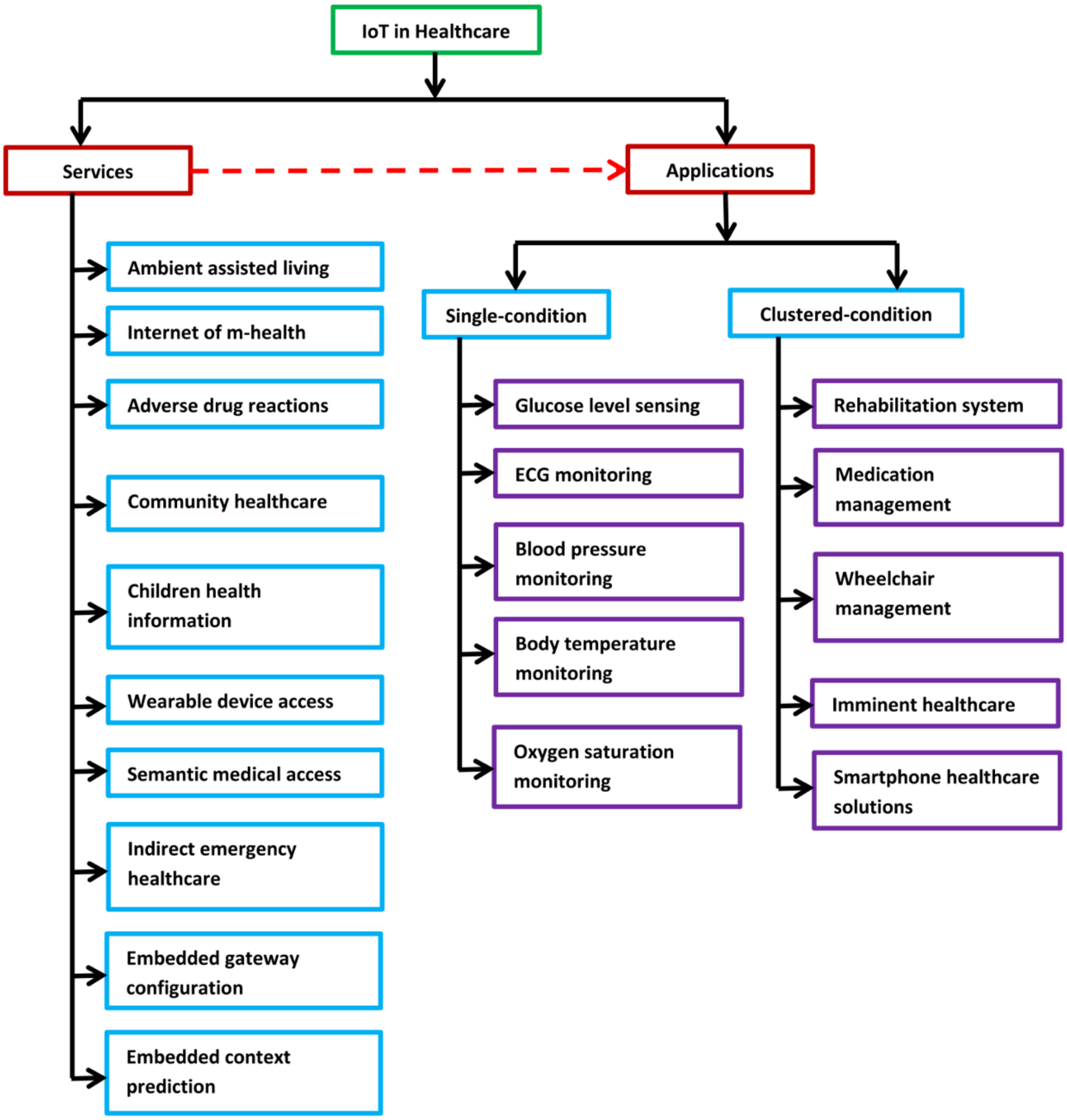

Figure 1: IoT healthcare applications and services (Islam et al., 2015)

2.5.1 *Indirect emergency healthcare*

Medical emergency situations occur regularly. These emergencies range from minor incidents to complicated healthcare situations such as accidents (vehicle, train, ship, aviation, etc.), environmental emergencies (tornado, earthquake, tsunami, etc.) and fire, which is commonly experienced in South Africa. An integrated system which offers IoT solutions including information availability (e.g. identification of the person on the scene, linkage with their stored medical records, including medical history), notifications (this notification can include the notification of the people kept in the systems records as emergency contact people, local medical centres where the patient needs to be transferred for treatment, ambulance services, and fire emergency services), post-accident action (e.g. notification of the ambulances about the incident and its location, its severity, and linkage to the hospital to prepare the bed, operating room, and the medical personnel to be ready for the patients who are going to be transferred to the hospital), and record keeping (an integrated highly secured system where people can be identified and their records are available to any medical centre) has emerged as indirect emergency healthcare (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.5.2 *Ambient assisted living*

Elderly people need to be cared for. This has led to the emergence of Ambient Assisted Living (AAL). AAL, with its technical support systems, has enabled independence and safe lifestyles amongst the elderly. This is by utilising Keep In Touch (KIT) devices, smart objects and technologies to facilitate telemonitoring processes (Carnaz & Nogueira, 2016; Friess & Vermesan, 2015; Islam et al., 2015; Sundmaeker, Guillemin, Friess, & Friess, 2010). Should an event be triggered, Closed Loop Healthcare Services use KIT technology to establish communication channels, an important aspect in AAL, between the elderly, their environment and various caregivers such as doctors, family, and mobile care providers (Carnaz & Nogueira, 2016; Islam et al., 2015). This combination has resulted in an applied IoT infrastructure, useful and accepted by the elderly. Reports have shown that through this combination of KIT and Closed Loop Healthcare, a central AAL paradigm can be realised through the IoT, where the elderly from the comfort of their homes can communicate to the outside world in an intelligent manner (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.5.3 *The Internet of m-health Things (m-IoT)*

Diabetes is one of the major chronic disease problems worldwide with major economic and social impact (Carnaz & Nogueira, 2016; Gapchup et al., 2016; Islam et al., 2015). To use IoT to resolve this challenge, an amalgamated concept of Internet of m-health Things (m-IoT) was introduced. M-IoT matches the functionalities of m-health and IoT for new and innovative future applications (Carnaz & Nogueira, 2016; Kumari, López-benítez, Myoung, Kim, & Minhas, 2016; Takpor & Atayero, 2015). M-health consists of computing, medical sensors, and communication networks for healthcare services (Carnaz & Nogueira, 2016; Kumari et al., 2016; Takpor & Atayero, 2015). It is a healthcare connectivity model that connects the 6LoWPAN with evolving 4G networks for Internet-based m-health services (Begum & Begum, 2017; Islam et al., 2015). This is the backbone of applications, such as glucose level sensing, through the use of IoT.

2.5.4 *Adverse drug reaction*

Adverse drug reaction (ADR) is an injury emanating from taking a medication (Carnaz & Nogueira, 2016; Niranjana & Balamurugan, 2015; Whitmore et al., 2015). This can happen after a single dose of a medical drug, a prolonged administration, or as a result of a combination of two or more different drugs. Due to ADR not being specific to medication of a particular disease, there has been an IoT solutions development to resolve some the identified challenges emanating from ADR. One of the IoT solutions is using the pharmaceutical intelligent information system which stores the patient healthcare records (Islam et al., 2015). The pharmaceutical system and the barcoded/NFC-enabled devices checks the compatibility of the drugs with the patient's profile to eliminate the possibly of ADR.

2.5.5 *Community healthcare*

One of the prominent challenges of healthcare is the sharing of healthcare records (Behmann & Wu, 2015). This means that if the patient goes from one healthcare centre to the next, a new file is created and it is disjoined with the previous health centre. To resolve this challenge, the concept of community healthcare (CH) emerged. CH also needs a network that enables the devices to communicate with the Internet (Carnaz & Nogueira, 2016; Islam et al., 2015). This is an IoT enabled network covering an area around the local community. It can be an IoT network covering municipality, residential area, town or a rural community. The concentration of such a network creates a cooperative network structure. This network structure can be viewed as a virtual hospital (Islam et al., 2015). The IoT solution brought about by this structured IoT network is to share medical records in the highly secured environment between community healthcare centres to resolve the challenge of medical records.

2.5.6 *Children health information*

Often, for different reasons, the community and families need to be aware of children suffering from emotional, behavioural or mental problems. This has led to a requirement for awareness amongst the stakeholders. Children's health information (CHI) is an IoT service which includes an interactive totem placed in a parasitic ward offering CHI services aimed at educating, amusing and empowering hospital children (Islam et al., 2015). As part of the CHI service, an IoT based m-health service is used to encourage children to acquire good nutrition habits, assisted by their parent and teachers.

2.5.7 *Wearable devices access*

With the emergence of diverse non-interactive wearable sensors and wearable devices with a set of features appropriate for IoT architecture, an interoperability challenge has emerged (Friess & Vermesan, 2015; Herselman & Botha, 2016; Niranjana & Balamurugan, 2015). Wearable device access is fixing this problem by providing a prototype system for a variety of healthcare applications through various mobile computing devices (Carnaz & Nogueira, 2016; Islam et al., 2015). This involves an activity recognition method based on mobile devices for remote monitoring of patients, remote monitoring systems using wearable devices and Bluetooth low energy (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.5.8 *Semantic medical access*

Medical sensors attached to people and devices produce a huge amount of data that is stored in the cloud (Niranjana & Balamurugan, 2015). The use of semantics and ontologies also requires sharing of a large amount of medical information and knowledge to make decisions (Friess & Vermesan, 2015; Islam et al., 2015; Whitmore et al., 2015). IoT healthcare applications are therefore required to, not only interoperate, but also manage this flow of data. This has led to the emergence of Semantic medical access (SMA). With SMA, applications employ medical rule engines to analyse massive amount of sensor data stored in the cloud (Carnaz & Nogueira, 2016; Islam et al., 2015). This data is then integrated and interoperated for emergency medical services.

2.5.9 *Embedded gateway configuration*

Interconnectivity between network nodes (to which the devices are connected), the Internet (backbone for the cloud services such as the required grid computing) and other medical equipment is required for IoT-based healthcare. This requirement involves common integration features which need to be present in an IoT gateway. This is where embedded gateway configuration (ECG) has emerged. ECG offers, among other things, automated and intelligent monitoring of the devices and systems, and standardisation of how gateways are implemented and integrated for the seamless communication of the whole system (Carnaz & Nogueira, 2016; Islam et al., 2015; Mukhopadhyay, 2014).

2.5.10 *Embedded context prediction*

In the ubiquitous healthcare system, context-aware healthcare applications over the IoT network are required (Carnaz & Nogueira, 2016; Friess & Vermesan, 2015; Whitmore et al., 2015). Developers of these applications also require the framework to have appropriate mechanisms for interoperability and usability.

This is where embedded context prediction (ECP) emerged. ECP offers a framework to ensure applications are working, and integrated to the IoT network and to the whole IoT healthcare ecosystem (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.6 The Internet of Things healthcare applications

The Internet of Things services discussed above enables the environment for the healthcare applications to flourish. These applications are those that deliver the results to all the necessary stakeholders. Therefore, IoT services are developers and service providers centric, whereas the applications are users and patients centric. Apart from applications covered in this section, wearables, various gadgets and other healthcare devices are discussed. These products offer innovation in the IoT healthcare for various necessary solutions.

2.6.1 *Glucose level sensing*

Diabetes mellitus, commonly referred to as diabetes, is a group of metabolic diseases in which there are high blood glucose (sugar) levels over a prolonged period (Sundmaeker, Guillemin, Friess, & Friess, 2010; Xu et al., 2014). Blood glucose monitoring is used to reveal individual patterns of blood glucose changes and assist in the planning of meals, activities, and medication times (Carnaz & Nogueira, 2016; Islam et al., 2015). The monitoring is done through the use of devices such as a glucose collector, a computer, a mobile phone and a background processor (Carnaz & Nogueira, 2016; Islam et al., 2015). Using m-IoT configuration for non-invasive glucose sensing in real-time, sensors from patients are linked through the network to relevant healthcare providers (Carnaz & Nogueira, 2016; Islam et al., 2015). If an event is triggered (for example, where the patient’s glucose level is becoming high), the relevant action is proactively taken.

2.6.2 *Electrocardiogram monitoring*

Symptoms such as chest discomfort, pressure or pain, palpitations, shortness of breath, diaphoresis, fainting, and dizziness are sometimes due to heart disorders. This is the challenge electrocardiogram (ECG) is aimed at resolving. This is achieved by monitoring electrical activity of the heart recorded by electrocardiography. The recording include the measurement of the simple heart rate and the determination of the basic rhythm, as well as the diagnosis of multifaceted arrhythmias, myocardial ischemia, and prolonged QT intervals (Carnaz & Nogueira, 2016; Kumari et al., 2016; Manyika et al., 2015). The application of the IoT to ECG monitoring provides all the information which leads to proactive solutions to the diagnoses.

2.6.3 *Blood pressure monitoring*

The higher the blood pressure is, the higher the risk of health problems in the future. If the blood pressure is high, it will put extra strain on the arteries and heart. Over time, this strain can cause the arteries to become thicker and weaker. To resolve this, a KIT blood pressure (BP) meter and an NFC-enabled KIT mobile phone are used for BP monitoring, based on IoT (Carnaz & Nogueira, 2016; Islam et al., 2015). It works by constantly sending the data over the IoT network to the cloud for analysis (Carnaz & Nogueira, 2016; Islam et al., 2015). If the event is triggered (for example, high bloody pressure trend), the appropriate action is then taken.

2.6.4 *Body temperature monitoring*

Body temperature provides critical information about onset of infection, antigenic responses, or whether the treatment is working. Body temperature monitoring uses a sensor embedded in the TelosB remote device, which records and transmits the variations in body temperature through RFID technology to a home gateway (Carnaz & Nogueira, 2016; Islam et al., 2015; Mukhopadhyay, 2014). The home gateway transmits the user's body temperature through RFID technology.

2.6.5 *Oxygen saturation monitoring*

The wearable pulse oximeter, Wrist OX2, has a functional ability to monitor a person's blood oxygen saturation in a non-invasive way (Islam et al., 2015). Some wearables come with Bluetooth technology and sensors which connect to a platform (Begum & Begum, 2017; Sreekanth & Nitha, 2016). It is used to monitor one's health over the IoT ecosystem.

2.6.6 *Rehabilitation system*

It is widely reported and believed that physical medicine and rehabilitation can enhance and restore the functional ability and quality of life of those with some physical impairment or disability. IoT-based smart rehabilitation systems are now dominating in becoming a better way to mitigate problems associated with aging populations and the shortage of health professionals (Carnaz & Nogueira, 2016; Gapchup et al., 2016; Islam et al., 2015). IoT has bought the solution into reality which automates the design and reconfiguration of such a rehabilitation system, enabling it to respond to the patient's requirements rapidly (Carnaz & Nogueira, 2016; Islam et al., 2015). This is done by aiding systems in further understanding the symptoms and medical resources, which helps to create a rehabilitation strategy and automatically reconfigure medical resources according to patients' specific requirements quickly (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.6.7 *Medication management*

Healthcare is facing noncompliance problems and huge financial waste globally, due to patients not adhering to their prescribed medications. Patients also die due to not following the medication prescription. IoT is addressing the problem by introducing IoT-based medication management through intelligent packaging method for medication boxes (Islam et al., 2015; Manyika et al., 2015; Revathi et al., 2015). The solution comes with wireless controlled sealing based on delamination materials. The solution use RFID to identify the package and at specific time intervals, the weight of the package is sent to the cloud to check if the patient has taken the medication or not (Carnaz & Nogueira, 2016; Islam et al., 2015). Should it be found that the weight of the medical package is similar in different intervals where the patient was expected to take the medication, an alert is send to the relevant people to notify them of the situation (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.6.8 *Wheelchair management*

Patients in wheelchairs suffer many difficulties. Some of them are due to their mobility and lack of fitness as they are mostly sitting down in the wheelchair. The worst thing that can ever happen to the wheelchair patient is to drive their own wheelchair in a rough environment. IoT has brought a solution by putting the sensors on the wheelchair to measure vital signs (Behmann & Wu, 2015; Carnaz & Nogueira, 2016; Stankovic, 2014). With the vital signs measured and analysed over the cloud, the relevant people can be notified for any action needs to be taken. The IoT solution has also been invented to deal with the unnecessary movements and vibrations of the wheelchair (Behmann & Wu, 2015; Carnaz & Nogueira, 2016; Stankovic, 2014). If this happens, the IoT system instantaneously sends notification to the caregivers to come for the patient’s assistance.

2.6.9 *Imminent healthcare solutions*

Today there are many portable devices being used. However, these devices might not yet be integrated into the IoT network. That is, it is a matter of time before these devices are converted into IoT devices. This phenomenon has also kept pace with the growing demand for IoT-based services across the world. Most of these devices today are portable diagnostic devices that are globally being used daily for medical care, with conventional connectivity. An imminent healthcare solution is required to integrate these devices into the IoT network (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.6.10 *Healthcare solutions using smartphones*

Today, the use of smart phones is high (GSM Association, 2014). Smart phones are everywhere and are beginning to do everything technological. The healthcare sector has also started integrating technology into their practices. They are being used for, apart from other things, disease management, records tracking, research and clinical referencing (Behmann & Wu, 2015; Friess & Vermesan, 2015; Jamalipour et al., 2016). Many healthcare providers around the world have also started developing mobile applications unique to their practice which further promotes patient engagement (Carnaz & Nogueira, 2016; Islam et al., 2015). Some of these smart phone applications include electronic health records, disease management, clinical referencing, and the patients' experience using social network (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.7 Global developments in healthcare-based IoT

The global diffusion of IoT in the healthcare industry is imminent (Andreini, Crisciani, Cicconetti, & Mambrini, 2010; Hwang et al., 2016; Miraz et al., 2015). This has been championed by the continuous development of IoT healthcare products and technologies. The diffusion has been led by entrepreneurs and venture capitalists' firms alike who have ensured that the industry develops (Bien & Selvanathan, 2014; Manyika et al., 2015; OECD, 2015a). The global market has experienced new start-ups and large firms which are developing IoT healthcare products and technologies (Jamalipour et al., 2016; OECD, 2015a; Scully, 2016). This section of the study discusses the global development by providing some of these products and technologies. Below is a summary of literature drawn from Islam et al. (2015)'s work, which discusses these global IoT developments.

Edisse is an Australian firm which provides lifestyle-based technologies. They are starting with bringing wearable technology to the aged care market to give the elderly back their independence. Edisse has a prototype wearable sensor for real-time tracking, fall detection and alerts developed mainly for the elderly. The device uses mobile data and GPS to track and report the location, and accelerometer to detect unusual movement such as a fall. Once triggered, an alert is send via the short messaging service (SMS) to third parties such as family members or caregivers.

Withings is a French company which was bought by Nokia in 2016. The firm has developed connected health devices, such as the Wi-Fi scale, blood pressure monitor, a high-definition wireless security camera, a smart sleep system, and a line of automatic activity tracking watches.

MiPlatform is an integrated all-in-one medical imaging and information management platform supporting cloud-based image storage and computerisation, web based 3D image post-processing and visualisation, and integrated telemedicine competence. MiPlatform was developed by a Chinese firm.

Jawbone is an American firm specialising in consumer technology and wearable devices, building hardware products and software platforms powered by data science. The firm has built sensors that helps people live better by providing personalised insight about their health status which includes activity tracking, sleep tracking, smart coaching and heart health sensing.

iHealth Lab, is a California, USA based company which designs and manufactures innovative, consumer-friendly, mobile personal healthcare products that connect to the cloud. The firm has developed IoT healthcare devices, including a wireless BP wrist monitor, a BP dock, a wireless body analysis scale, a wireless pulse oximeter and a wireless smart glucose-monitoring system. Similar technologies have been developed by Fuelband and ibitz.

In addition to the above developments in healthcare connected products, the following is a summary of the key IoT firms and their roles in the diffusion of IoT.

Cisco is an American firm which manufactures networking devices. They provide the network for IoT healthcare devices with advanced analytics. They also offer applications which integrate into the IoT healthcare network without compromising security. They have also worked with healthcare organisations to develop network architecture for the medical field.

Microsoft is an American software company. The firm has focused on using intelligent systems to uncover the potential of IoT-based healthcare solutions. Intelligent systems provide the backbone of technologies that allow the capture of health data from devices to ensure required connectivity. They also have business intelligence tools capable of extracting important insights from the collected data.

Google is an American search engine firm. The firm has opened its application code for an open-source physical web standard for IoT in an attempt to make it easier to communicate with connected medical devices.

Samsung is a Korean electronics firm. Together with the University of California, San Francisco, the firm has established a digital health innovation lab to develop new smart health technologies. Samsung has also worked with IMEC (a leading bio-sensing research institute headquartered at Belgium) to develop the Simband platform, an open reference design for sensor modules. The firm's IoT goal is a ubiquitous and seamless user experience for better health for everyone with no additional complexity.

Qualcomm is an American multinational semiconductor and telecommunications equipment company that designs and markets wireless telecommunications products and services. The 2net Platform of Qualcomm Life offers a set of wireless health solutions that can capture and deliver health devices' data to integrated portals and databases from almost all wireless medical devices of users. The data can be stored in a system to integrate security and interoperability. Qualcomm's goal is to develop intelligent, intuitive, and innovative IoT healthcare solutions.

IBM, an American multinational technology firm redefines value and success in healthcare through the notion of smarter healthcare. IBM has helped to develop a set of IoT devices through partnerships for other renowned firms across the world. It focuses on a series of healthcare solutions such as connected home health, data governance for healthcare, and health analytics for healthcare providers.

Apple, an American technology company has publicly claimed IoT as the ultimate technology. The Apple watch can be considered a smart watch, a fitness tracker, or a heart monitor. The Memorial Hermann healthcare system relies completely on Apple's solutions to provide efficient and connected healthcare services focusing on secure access, physician gain, and better care.

GSMA, an association of mobile operators and related firms, has launched a connected living programme to bring the mobile industry and healthcare stakeholders together to deliver mHealth solutions over an intelligent and secure IoT network.

2.8 IoT healthcare challenges

The diffusion of IoT in healthcare needs the designing and implementation of various IoT healthcare services with their associated technologies and architectures. As IoT is an emerging technology, this has come with many challenges that need to be resolved for IoT diffusion. This section briefly discusses both explored and unexplored IoT healthcare services challenges.

2.8.1 *Standardisation and implementation challenges*

The diffusion of IoT around the globe came with a rapid evolution of the IoT market, offering a variety of IoT solutions to different challenges (Hwang et al., 2016). Additionally, because of this opportunity, large amounts of funding are being deployed at IoT start-ups (Whitmore et al., 2015). This has led to the industry focusing on manufacturing and producing the right types of hardware to enable those solutions (Carnaz & Nogueira, 2016; Islam et al., 2015). Most IoT solution providers have been hard at work building all components of the stack, from the hardware devices to the relevant cloud services (Carnaz & Nogueira, 2016; Friess & Vermesan, 2015; Islam et al., 2015). This has resulted in a lack of consistency and standards across the cloud services used by the different IoT solutions (Friess & Vermesan, 2015; Kulkarni & Sathe, 2014; Vermesan et al., 2016). Therefore, there is no interoperability between different applications and IoT service providers.

The challenges facing IoT standardisation can be divided into four categories, namely platform, connectivity, business model and applications. They are briefly discussed below.

Platform: this includes the form and design of the products (user interface/user experience), analytics tools used to deal with the massive volume of data streaming from all products in a secure way, and the need for scalability which means that wide adoption of protocols like IPv6 in all is necessary (Islam et al., 2015; Ndubuaku & Okereafor, 2015).

Connectivity: this includes all forms of connecting the people and devices. This includes wearables, smart cars, smart homes, and in the big scheme, smart cities (Friess & Vermesan, 2015; Islam et al., 2015).

Business model: a standardised business model is a big motivation for starting, investing in, and operating any business. Currently, there is no business model for IoT. The model need to consider the requirements of e-commerce; vertical markets, horizontal markets and consumer markets. However, business models are always challenged by the regulatory and legal environment of the specific jurisdiction (Fan & Zhou, 2011; Friess & Vermesan, 2015; Govindarajan & Ramamurti, 2013).

Applications: there are three functions required for applications: control "things", collect "data", and analyse "data". IoT needs applications to drive the business model using a unified platform (Chen et al., 2014; Friess & Vermesan, 2015; Kulkarni & Sathe, 2014).

The four categories are interrelated. For IoT to be diffused, they are all required to work interactively (Hwang et al., 2016). If one of them is missing, it will break the model and stall the standardisation process. A lot of work is needed to reach standardisation (Islam et al., 2015; Kumari et al., 2016; Madakam et al., 2015). The study has discovered that there has been a lot of development trying to standardise, to this end, there has not been any dominant and widely accepted standard for IoT.

2.8.2 *The application development process*

For the successful integration of IoT, the developed applications need to be interoperable with the IoT healthcare ecosystem. There are four basic steps in developing a mobile app on the android platform, namely the setup, development, debugging and testing, and publishing (Mukhopadhyay, 2014). Other platforms also follow similar development processes. In the process of healthcare app development, there has not been any authorised body or organisation of medical experts for ensuring that apps of acceptable quality are developed and deployed (Islam et al., 2015). This also makes the regular updates on healthcare apps based on the due consideration of recent advances in medical science, which is vital, suffer (Carnaz & Nogueira, 2016; Islam et al., 2015).

2.8.3 *Technology transition*

IoT has brought about a lot of innovation in healthcare (Sreekanth & Nitha, 2016; Whitmore et al., 2015). It has modernised the processes and brought about automation and agility (Sreekanth & Nitha, 2016; Whitmore et al., 2015). This came at a price. To date, there has not been any standardisation to seamlessly integrate the legacy healthcare systems and the IoT-based systems (Friess & Vermesan, 2015; Ndubuaku & Okereafor, 2015). There is a requirement for seamless integration between those two worlds for the diffusion of IoT in healthcare (Hwang et al., 2016).

2.8.4 *The low-power protocol*

One of the requirements for the IoT operation is low-power devices with their associated technologies (Carnaz & Nogueira, 2016; Jamalipour et al., 2016; Mukhopadhyay, 2014). This is because sometimes these devices are placed in areas where there are no means to charge them and therefore they need longer life without worrying about their power. There has not been one low-power protocol which has been developed for this purpose (Carnaz & Nogueira, 2016; Jamalipour et al., 2016; Mukhopadhyay, 2014.

2.8.5 *Network type*

To date, there has not been one adopted network architecture to suit the requirements of an IoT healthcare network (Carnaz & Nogueira, 2016). Carnaz and Nogueira (2016) further argued that this is because the network has different distinct requirements such as data-, service-, and patient-centric architectures. In the data-centric architecture, the healthcare structure can generally be separated into objects, based on captured health data. In a service-centric architecture, the healthcare structure is allocated by the assembly of characteristics that they must provide. In the patient-centric architecture, healthcare systems are divided according to the involvement of patients and their family members they consider for treatment. In this regard, answering the question of what network type is appropriate for IoT-based healthcare solutions becomes an open issue which is still to be resolved.

2.8.6 *Scalability*

The diffusion of IoT means the systems need to be scalable to cater for the massive uptake of the IoT services (Carnaz & Nogueira, 2016; Niranjana & Balamurugan, 2015; Sathi & Gayathri, 2016). It is therefore important that when the IoT system is deployed, it needs to consider the current and future expansion and requirements. Should the system not be scalable, it will not be able to accommodate future expansion when shifts in technology occur. This will lead to unusable systems and devices that must either be replaced or augmented, and this is a challenge that need to be fixed (Carnaz & Nogueira, 2016; Niranjana & Balamurugan, 2015; Sathi & Gayathri, 2016). To date, there has not been a standard architecture widely accepted for scalable IoT systems and solutions.

2.8.7 *The Quality of Service (QoS)*

Healthcare services are based on authentic, timely and precise data (Carnaz & Nogueira, 2016; Friess & Vermesan, 2015). The healthcare environment is highly time sensitive and require QoS guarantees in terms of reliability, maintainability, and the service level (Carnaz & Nogueira, 2016; Islam et al., 2015; Petäjäjärvi et al., 2016). There is currently no quantitative measurement of each such parameter within the IoT framework(Carnaz & Nogueira, 2016). Carnaz and Nogueura (2016) believe that in medical situations, any type of system disaster can put lives at danger, therefore system availability and robustness are central to offering QoS guarantees.

2.8.8 *Data protection*

With the amount of data these healthcare devices will generate, the challenge has emerged which involves navigating these data and identifying suspicious traffic over the network (Carnaz & Nogueira, 2016; Kumari et al., 2016; Vujovic et al., 2015). The missed incident because of the malicious data can have devastating effects. Therefore, the protection of captured health data from various sensors and devices from illegitimate access is crucial to the network (Carnaz & Nogueira, 2016; Kumari et al., 2016; Vujovic et al., 2015). Therefore, stringent policies and technical security measures should be introduced to share health data with authorized users, organisations, and applications. There is no optimal algorithm for collaborating between protection, detection, and reaction services to prevent various attacks, threats, and vulnerabilities (Carnaz & Nogueira, 2016).

2.8.9 *Mobility*

The mobility of patients through the IoT healthcare network must be ensured (Kulkarni & Sathe, 2014; Kumari et al., 2016; Sathi & Gayathri, 2016). This is because patients need to seamlessly be connected anywhere, anytime. Should this connectivity not be guaranteed, there will be a gap in data collection and therefore compromise data integrity and analysis. This is an open challenge thus far as, like most standardisations, it has not yet been solved.

2.8.10 *Ecological impact*

The diffusion of IoT-based healthcare services requires many biomedical sensors embedded in semiconductor-rich devices (Carnaz & Nogueira, 2016; Sundmaeker, Guillemin, Friess, & Friess, 2010). These sensors and devices, at times, include rare earth metals and severely toxic chemicals (Carnaz & Nogueira, 2016). They therefore have substantially unfavourable impacts on the environment, users, and human health (Carnaz & Nogueira, 2016; Sundmaeker, Guillemin, Friess, & Friess, 2010). It is for this reason that guidelines are needed for device manufacturing, the use of devices, and their proper disposal.

2.9 IoT healthcare security

The IoT in healthcare has grown rapidly. In the next several years, the healthcare sector is expected to witness the diffusion of the IoT and to flourish through new eHealth IoT devices and applications (Friess & Vermesan, 2015; Govindarajan & Ramamurti, 2013; Islam et al., 2015). Healthcare devices and applications are expected to deal with vital private information, such as personal healthcare data (Behmann & Wu, 2015; Friess & Vermesan, 2015; Islam et al., 2015). In addition, such smart devices may be connected to global networks for access anytime, anywhere. As such, the IoT healthcare domain may be a target of attackers (Behmann & Wu, 2015; Friess & Vermesan, 2015; Islam et al., 2015). To facilitate the diffusion of the IoT in the healthcare domain, it is critical to identify and analyse distinct features of IoT security and privacy, including security requirements, vulnerabilities, threat models, and countermeasures, from the healthcare perspective (Gapchup et al., 2016; Hiremath et al., 2014; Sathi & Gayathri, 2016). The following subsections are based on the literature from Carnaz and Nogueira (2016, Hiremath et al. (2014), and Islam et al. (2015).

2.9.1 *Security requirements*

Security requirements for IoT-based healthcare solutions are no different to those in standard communications scenarios. As such, to achieve secure services, there is a need to focus on the following security requirements.

Confidentiality

Confidentiality ensures that only authorised users of medical information are permitted to access the data. In addition, confidential messages resist revealing their content to eavesdroppers.

Integrity

Data integrity involves maintaining the tempering of data. In medical world, integrity ensures that received medical data are not tempered in transit. In addition, this ensures the integrity of stored data and content by ensuring that the stored data is not compromised in anyway or form.

Authentication

Authentication enables an IoT health device to ensure the identity of the peer with which it is communicating.

Availability

Availability ensures the continuous accessibility of IoT healthcare services to authorised parties when needed.

Data freshness

Data freshness implies that the sensed data is recent. Due to IoT healthcare network providing some time fluctuating measurements, there is a requirement to ensure that each message is therefore fresh. Data freshness implies that each data set is recent with no adversary old messages.

Non-repudiation

The requirement of non-repudiation is to ensure that a network node cannot deny sending a message sent earlier.

Authorisation

Authorisation ensures that only authorised nodes are accessible for network services or resources.

Resiliency

Resilience, in principle, is the ability to provide and maintain an acceptable level of service in the face of faults and challenges. The resiliency requirement is such that should some interconnected health devices be compromised; a security scheme should still protect the network and associated information from any attack.

Fault tolerance

In principle, fault tolerance is the requirement that, even when the network is under attack, there should still be a certain level of accessibility and services provided.

Self-healing

A self-healing environment is aimed at minimising the human effort and cost involved in locating the causes of failure in complex systems. For example, even if the medical device in an IoT healthcare network fails or runs out of energy, the remaining or collaborating devices should enable a minimum level of security.

2.9.2 *Security challenges*

The Internet of Things security requirements are not guaranteed by traditional security techniques; therefore, countermeasures are needed to address new challenges emanating from IoT. Challenges for secure IoT healthcare services include computational limitations of the devices, memory limitation, energy limitations of the devices, mobility of the devices, scalability, communication networks, multiplicity of devices, a dynamic network topology, a multi-protocol network, and dynamic security updates.

2.10 The potential of IoT in healthcare

According to the OECD (2015a), ICT manufacturing and ICT services globally are continuing to grow.

The use of the Internet has been increasing over the years (Internet World Stats, 2016; Mukhopadhyay, 2014). As per the statistics, the number of Internet users at 30 June 2016 exceeded 3.6 billion worldwide representing 49.2% penetration rate (Internet World Stats, 2016). The details of the users based on global geographical distribution are shown in the table below. Based on Table 1, the global Internet usage growth based on the population has grown by 900.4% in 16 years. This is a global opportunity for IoT as it fundamentally, from technological point of view, depends on the Internet to succeed.

Table 1: World Internet usage and population statistics June 30, 2016 (Internet World Stats, 2016)

World Regions	Population (2016 Est.)	Population % of World	Internet Users 30 June 2016	Penetration (% Population)	Growth 2000-2016	World Internet Penetration
Africa	1,185,529,578	16.2 %	339,283,342	28.6 %	7,415.6%	9.4 %
Asia	4,052,652,889	55.2 %	1,792,163,654	44.2 %	1,467.9%	49.6 %
Europe	832,073,224	11.3 %	614,979,903	73.9 %	485.2%	17.0 %
Latin America / Caribbean	626,054,392	8.5 %	384,751,302	61.5 %	2,029.4%	10.7 %
Middle East	246,700,900	3.4 %	132,589,765	53.7 %	3,936.5%	3.7 %
North America	359,492,293	4.9 %	320,067,193	89.0 %	196.1%	8.9 %
Oceania / Australia	37,590,704	0.5 %	27,540,654	73.3 %	261.4%	0.8 %
WORLD TOTAL	7,340,093,980	100.0 %	3,611,375,813	49.2 %	900.4%	100.0 %

Based on Table 1 above, Africa has seen 7,415.6% population Internet usage growth rate in that 16 years' duration, outperforming any other continent. While Africa has the highest growth rate (Figure 1), it however has the lowest penetration rate as shown in Figure 2 below. This, however, represents Internet based opportunities and challenges, including in the health care sector.

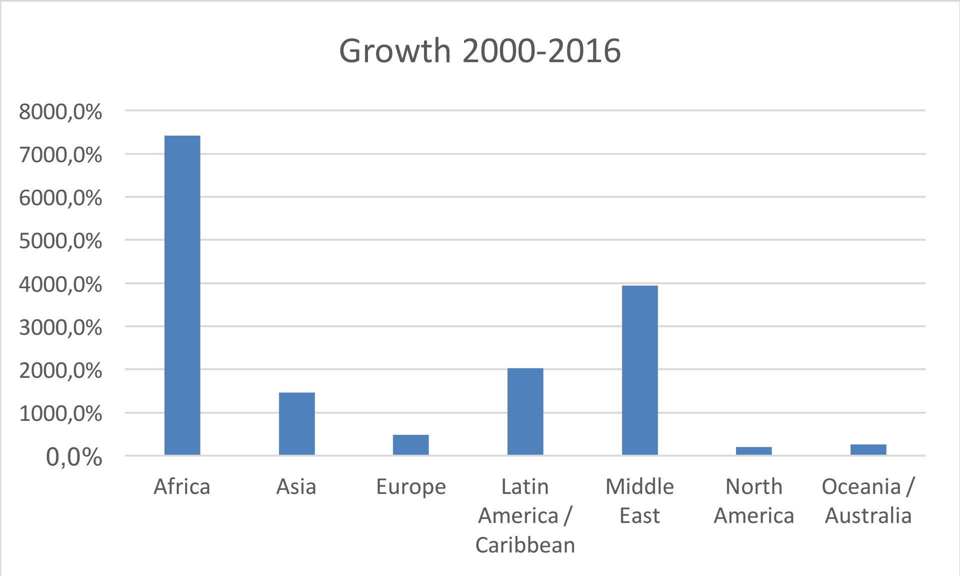

Figure 2: World Internet growth 2000-2016 (Internet World Stats, 2016)

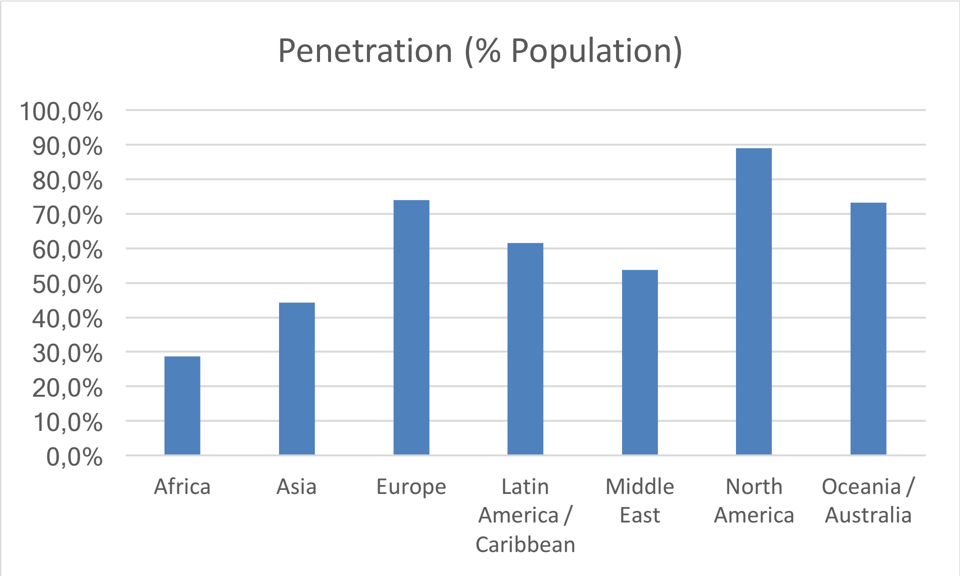

Figure 3: World Internet penetration (Internet World Stats, 2016)

Table 2 below shows the data for the African continent. Based on Table 2, Africa has over 1.1 billion people. Of that 1.1 billion, only 28.6% are connected to the Internet.

Appendix A shows the complete Africa 2016 population and the Internet users statistics.

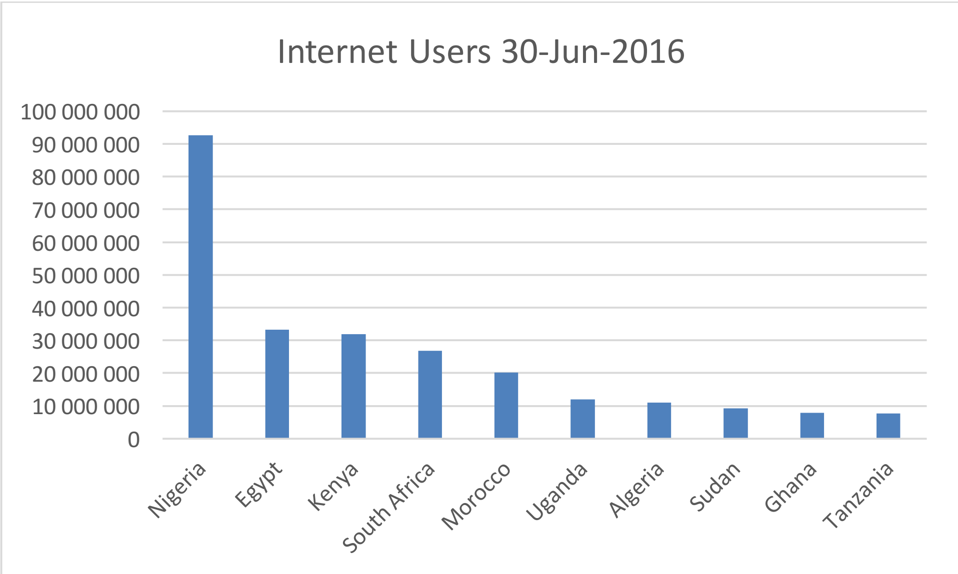

Figure 4: Top 10 African Countries Internet usage (Internet World Stats, 2016)

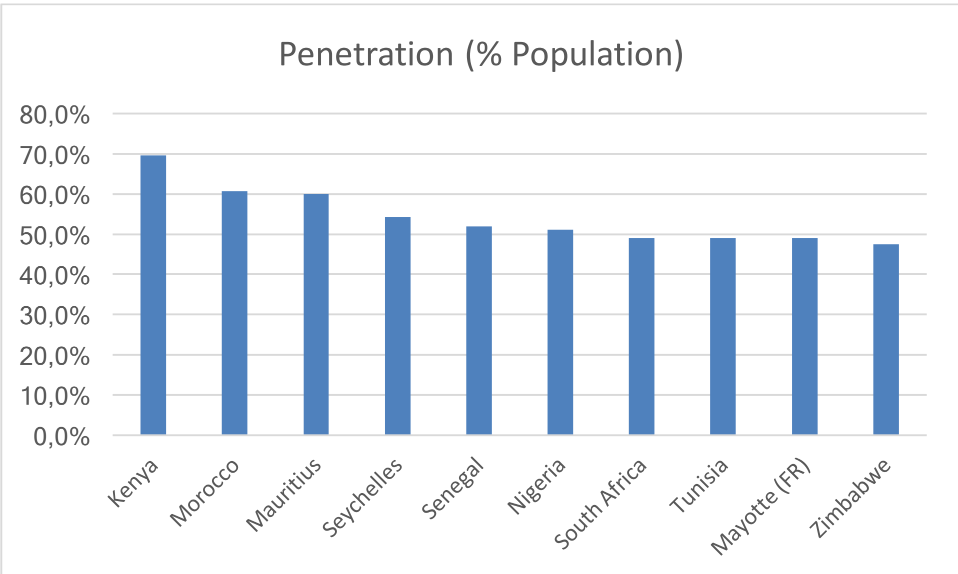

Figure 5: Top 10 African countries Internet penetration (Internet World Stats, 2016)

Though the African Internet penetration is 28.6%, South Africa is the fourth most enabled country; based on the penetration of the country population that is connected to the Internet, it has a 49% Internet penetration.

2.11 Global major success factors for IoT

Based on this study's literature review, the conditions that could allow IoT to succeed in different countries are under-researched. However, the Organisation for Economic Co-operation and Development (OECD), which is composed of 35 countries and five partners, has a mission to promote policies that will improve the economic and social well-being of people around the world by providing a forum in which governments can work together to share experiences and seek solutions to common problems. Though South Africa is not a member of the OECD, the country is one of the key partners. Brazil, India, Indonesia, the People's Republic of China and South Africa have been invited by the OECD to become key partners so that they can contribute to the work done by the organisation. The OECD (2015) has published an analysis of the digital economy and IoT development in these 40 countries. Most portions of this study in this section are based on the OECD (2015) report.

The conditions that underpin the success of IoT are closely interdependent (Friess & Vermesan, 2015; OECD, 2015b; Purfield, Im, & Inchauste, 2014; Rifkin, 2014b). The fundamental enabler is the high quality, accessible and available infrastructure used to enable communication within and across borders (Friess & Vermesan, 2015; OECD, 2015b; Purfield et al., 2014; Rifkin, 2014b). These provide the foundation for IoT to lay its applications and services based on new business models, enhanced production methods, and new collaborations (Friess & Vermesan, 2015; OECD, 2015b; Purfield et al., 2014; Rifkin, 2014b).

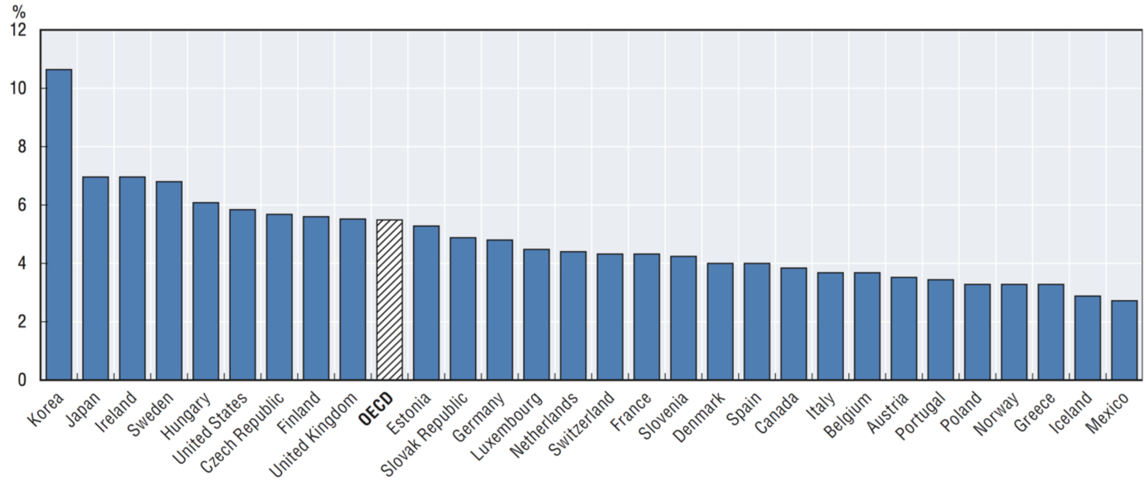

Figure 6: 2013 country share of ICT value added as a percentage of total value added (OECD, 2015a)

Some countries like Korea, Japan and Ireland are ahead in their success of using ICT to create value for their economies (Figure 6). Below are the summaries of the identified top 10 key conditions that allowed some of these countries to successfully implement the Internet of Things and to create value in their countries' digital economy.

2.11.1 *Access to the Internet*

As discussed in this literature review, the Internet is the fundamental enabler of IoT (Behmann & Wu, 2015; Friess & Vermesan, 2015; Minerva et al., 2015; Xu et al., 2014). Access to the Internet will enable IoT to be successful in unlocking the potential economic value, allow consumers to be able to consume the IoT products and services which in return, will make the IoT successful (Behmann & Wu, 2015; Friess & Vermesan, 2015; Minerva et al., 2015; Xu et al., 2014).

The Internet is accessed through broadband, fixed, mobile, wireless or any other new forms that enable communication and access through the Internet (Coetzee & Eksteen, 2011; Sundmaeker, Guillemin, Friess, & Woelffle, 2010).

The Internet World Stats (2016) compares South African Internet penetration against the world. At 49% Internet penetration based on total population, South Africa is well positioned compared to other countries such as Korea, Ireland, USA, Japan, etc. that have already successfully implemented IoT (OECD, 2015a).

To unlock access to the Internet, the study has found that countries have allocated sufficient spectrum to the operators and increased broadband capacity, coverage and resilience, and have invested substantially to the development of the Internet infrastructure (Atzori et al., 2010; OECD, 2015a; Vermesan & Friess, 2014)

South Africa still has spectrum allocation challenges that need to be resolved before they can allocate more spectrum to operators (OECD, 2015b). Mobile penetration is growing which has led to a majority of the people accessing the Internet through smart phones using mobile connectivity (GSM Association, 2014; OECD, 2015b). This has in part, been enabled by the price of mobile Internet connectivity being less than that of the fixed network (Gillwald, Moyo, & Stork, 2012). Moreover, the Internet speed on the mobile network is generally faster than that of the fixed network, even though it is cheaper than the fixed network (Gillwald et al., 2012).

The Internet is the main condition for IoT to succeed. The rest of the conditions are secondary to the Internet accessibility.

2.11.2 *Country-specific government economic digital strategy*

National digital strategies are developed across different sectors as the Internet permeates across all economic sectors of any country. They are designed to boost the country's competitiveness, economic growth and social wellbeing, an agenda which is common to the majority of the countries. Denmark has created the ICT strategy called the Growth Plan which is meant to support growth in their ICT sector and growth in the private sector (Regeringen, 2014). Germany created a strategy called Digital Agenda 2014-2017 which is centred around the exploitation of the ICT innovation to create further growth and employment (The German Federal Government, 2014). Italy developed a strategy called Digital Agenda 2014-2020 and Italian strategy for ultra-wideband which is aimed at economic and social growth through developing skills in business and it further intends to disseminate the digital culture amongst citizens through the growth in IoT (Presidenza del Consiglio dei Ministri, 2015). More countries which are leading in digitalisation and in IoT have also developed strategies which are aimed at the common goal of leveraging IoT to unlock the economic potential it offers (OECD, 2015a).

2.11.3 *Uptake of the Internet of Things products and services*

One of the conditions for IoT to succeed is the consumption of IoT products and services (OECD, 2015a). As discussed in this study, the products and services vary, and also solve different challenges, and the foundation of that consumption is the accessibility of the Internet itself.

Different countries like Germany, USA, Mexico, Egypt, etc. have created an environment to enable the products and services of IoT to thrive (OECD, 2015a). They have done that by providing regulation and policies that would allow infrastructure development, entrepreneurship and consumption of these goods and services (Ndubuaku & Okereafor, 2015; OECD, 2015a; Sundmaeker, Guillemin, Friess, & Woelffle, 2010).

Adoption of digital opportunities by business organisations, consumers and governments enabled by IoT is central to achieving economic and social benefits (resource planning software, cloud computing services, receive electronic orders, etc) (Chen et al., 2014; Ndubuaku & Okereafor, 2015; OECD, 2015a).

2.11.4 *Strengthening of digital security and privacy*

Data security and privacy plays an important role in the deployment of IoT deployment (Coetzee & Eksteen, 2011; Minerva et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014). Because IoT systems produce and involve personal identifiable information, it is critical therefore, to have data security and privacy to allow consumers to consume the services offered and therefore, in turn, to enable IoT to thrive (Coetzee &

Eksteen, 2011; Minerva et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014).

The responsibility of this digital security and privacy lies with different stake holders. The government is responsible for creating policies which will ensure digital security and privacy (Coetzee & Eksteen, 2011; Minerva et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014). The systems owners of IoT are also responsible for ensuring that their systems are well built to cater for a high level of digital security and privacy (Coetzee & Eksteen, 2011; Minerva et al., 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014).

2.11.5 *Skills development, education and training*

The Internet of Things, as a new phenomenon, will need new skills to develop and sustain it (Behmann & Wu, 2015; OECD, 2015a). However, this will be built on top of most skills which have already been learned with regard to the Internet, applications development and infrastructure development.

Countries that have taken the advantage of the transition to IoT have embraced skills development as one of the key factors to enable the country to be successful in its digital strategy (Behmann, 2015; Macgillivray et al., 2016; Presidenza del Consiglio dei Ministri, 2015; The German Federal Government, 2014). Governments have integrated their education and training with IoT to create knowledge bases (OECD, 2015a; Presidenza del Consiglio dei Ministri, 2015; The German Federal Government, 2014). This knowledge base has assisted in the creation of policies, being innovative, and the consumption of the services created by IoT (Behmann & Wu, 2015; OECD, 2015a).

2.11.6 *Governments create policies*

Naturally, IoT is a disruptive technology (Berg et al., 2014; Friess & Vermesan, 2015; Vermesan & Friess, 2014). It requires a change in policies to create an environment to enable it to thrive (Berg et al., 2014; Friess & Vermesan, 2015; Vermesan & Friess, 2014). Governments across the globe that have been successful in their implementation of IoT have created policies to enable the environment for IoT to thrive (OECD, 2015a).

The OECD (2015a) has done a study of the policy prioritisation as shown in Figure 7. The figure is a good depiction of the enablers of IoT as it covers most of the requirements for it to thrive.

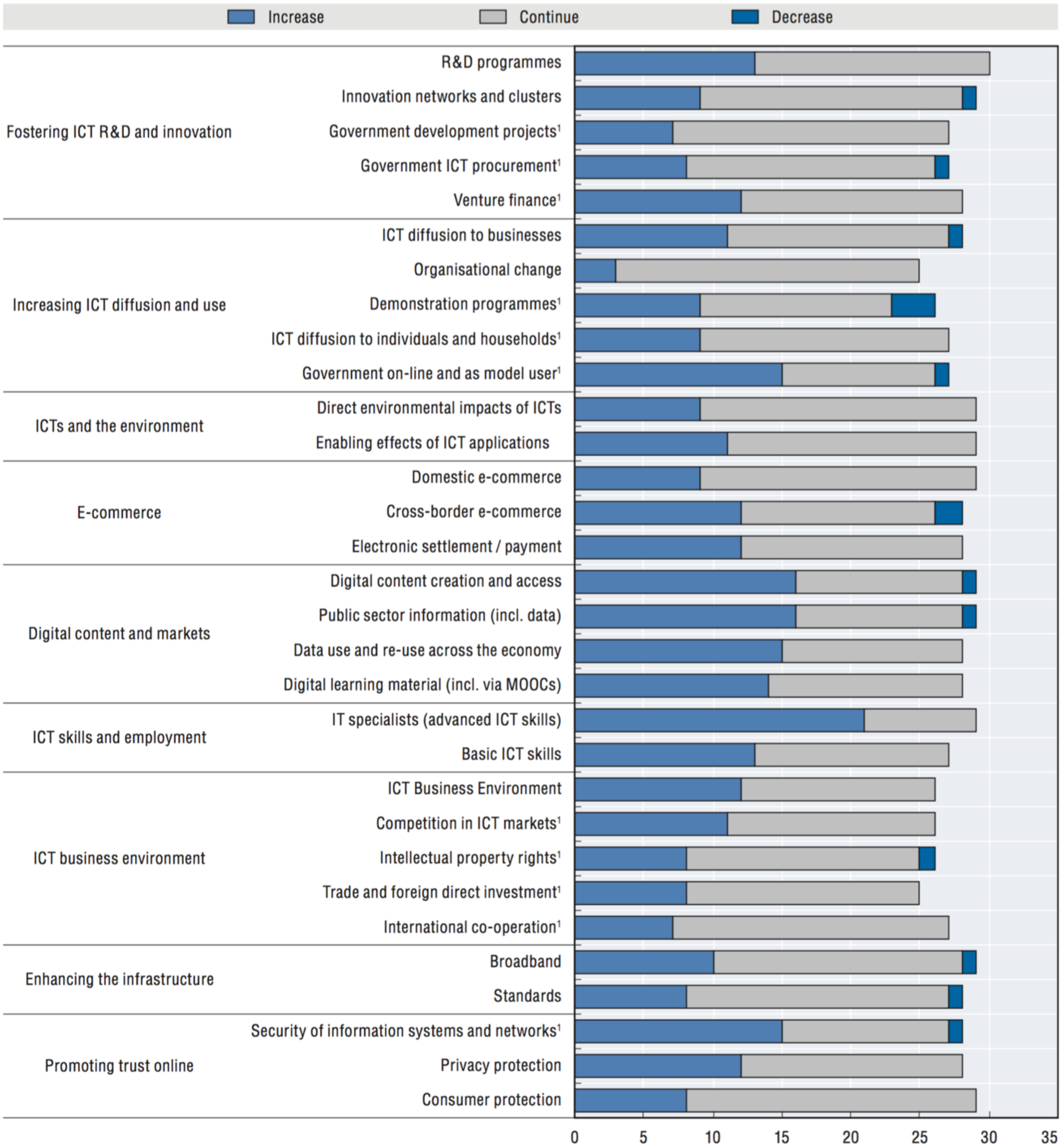

Figure 7: Evolution of ICT policy priorities based on number of responses (OECD, 2015a)

2.11.7 *Development of ICT sector: new technologies, goods and services*

Countries such as Kenya, Egypt, USA, Japan, China and EU have focused on developing the strategies that would develop the ICT sector.

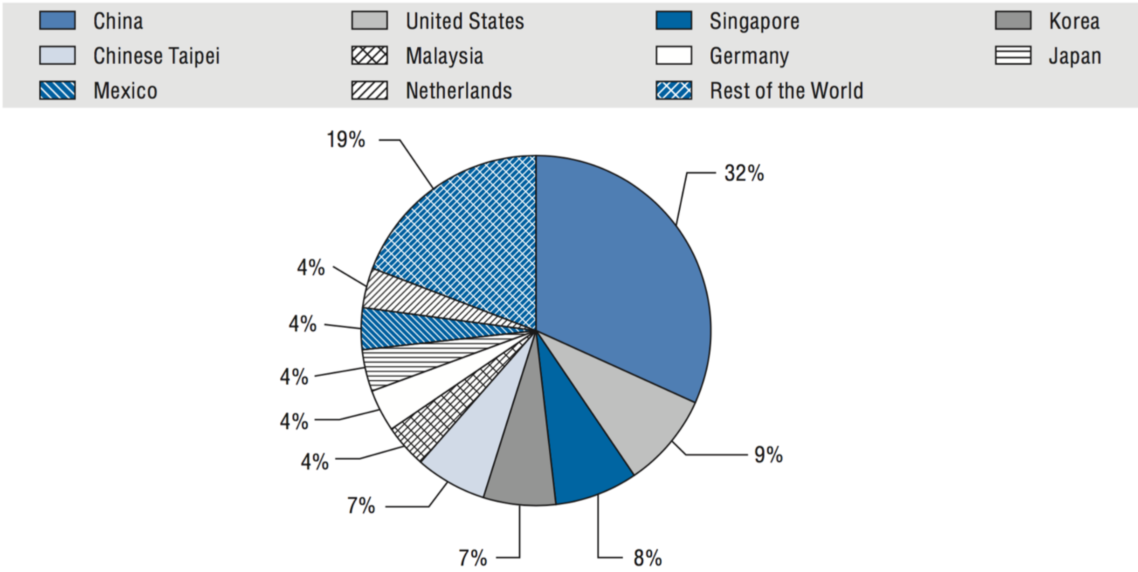

Figure 8: Top 10 world exporters of ICT goods (OECD, 2015a)

Of the top 10 ICT goods and services exporters in 2013 above, China is leading with 32% market share.

2.11.8 *Foster entrepreneurship and employment*

At the centre of most of the country's strategies is social growth, economic growth and employment (OECD, 2015a). These are created mostly by fostering entrepreneurship (Jamalipour et al., 2016; Manyika et al., 2015; OECD, 2015a; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014). In the USA, the country has been seeing a growth in the investment of the venture capitalist as shown in Figure 9 below (OECD, 2015a). The USA is in the 10 global countries that are adding value to their economy successfully using ICT (OECD, 2015a). A success in IoT entrepreneurship will add employment opportunities (Berg et al., 2014; Friess & Vermesan, 2015; OECD, 2015a; Olsen, 2008; Vermesan & Friess, 2014).

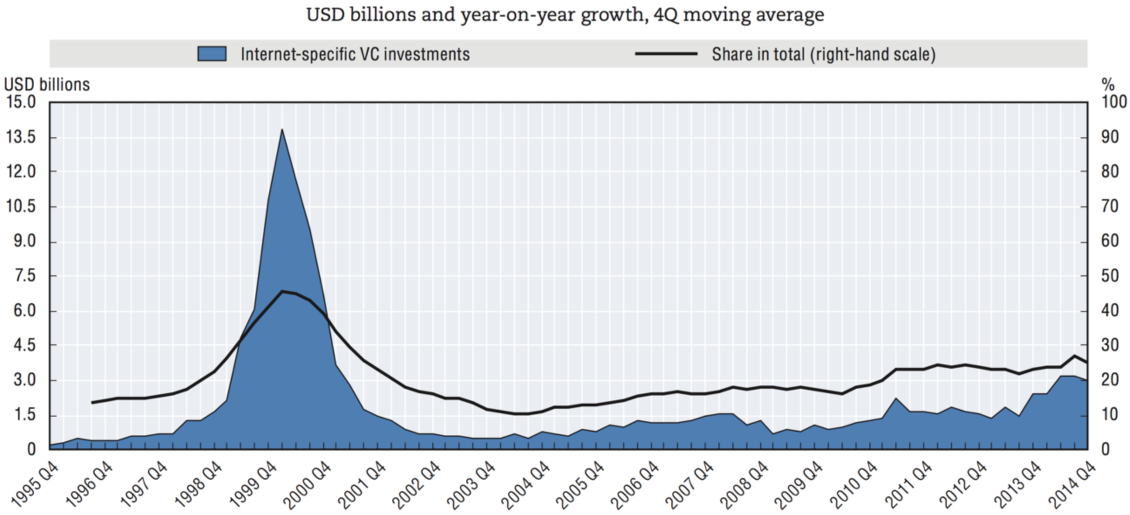

Figure 9: USA 1995-2014 venture capitalist investment growth (OECD, 2015a)

2.11.9 *Protect competition*

To maximise the potential of IoT and the digital economy for productivity, innovation, inclusive growth and jobs creation, some governments have created policies to protect their market against competition (OECD, 2015a; Rifkin, 2014a; Tapscott, 1996). One of the common methods the governments have used was to lower artificial barriers of entry into the Internet of Thing market (Coetzee & Eksteen, 2011; Schenkel & Stev, 2012; The German Federal Government, 2014).

2.11.10 *Fostering ICT research, development and innovation*

The study has observed that the countries that have been successful in their implementation of IoT have fostered research, development and innovation (Herdon et al., 2015; OECD, 2015a; Vermesan et al., 2016).

Below in Figure 10 is the 2013 business expenditure in research and development as a percentage of the GDP. Compared to Figure 8, the study has observed that the research, development and innovation in those counties had a direct link to adding economy value into those countries.

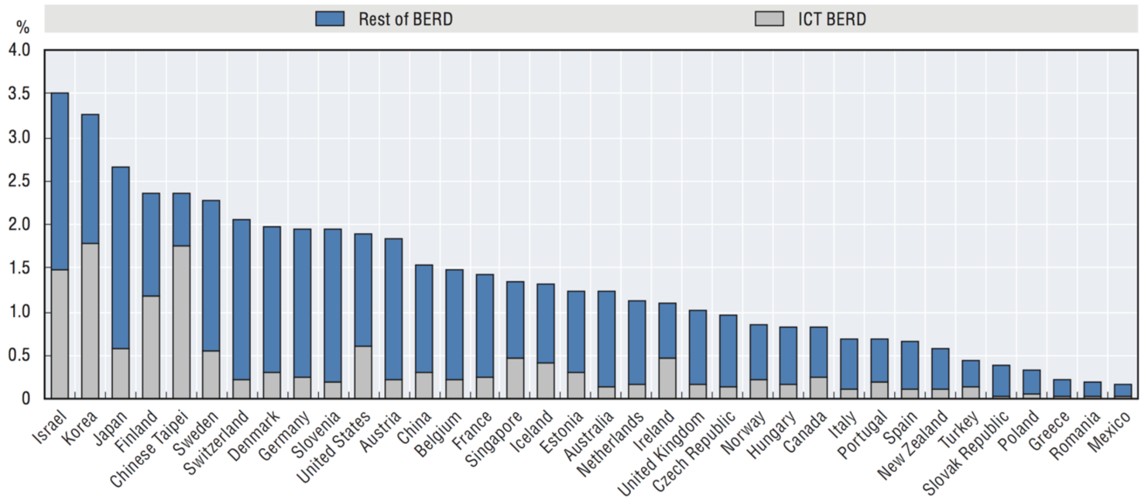

Figure 10: 2013 Business expenditure in R&D as percentage of GDP (OECD, 2015a)

Innovation also drives the probability of IoT adoption and success (Herdon et al., 2015; OECD, 2015a; Vermesan et al., 2016). Figure 11 below shows the ICT related patents as a percentage of total Patent Cooperation Treaty (PCT) patent applications. Comparing to Figure 8, the study discovered that Korea, Japan, Ireland, Sweden and Finland are in the top 10 of both figures. The study therefore suggests that the countries which foster innovation become successful in adding economic value.

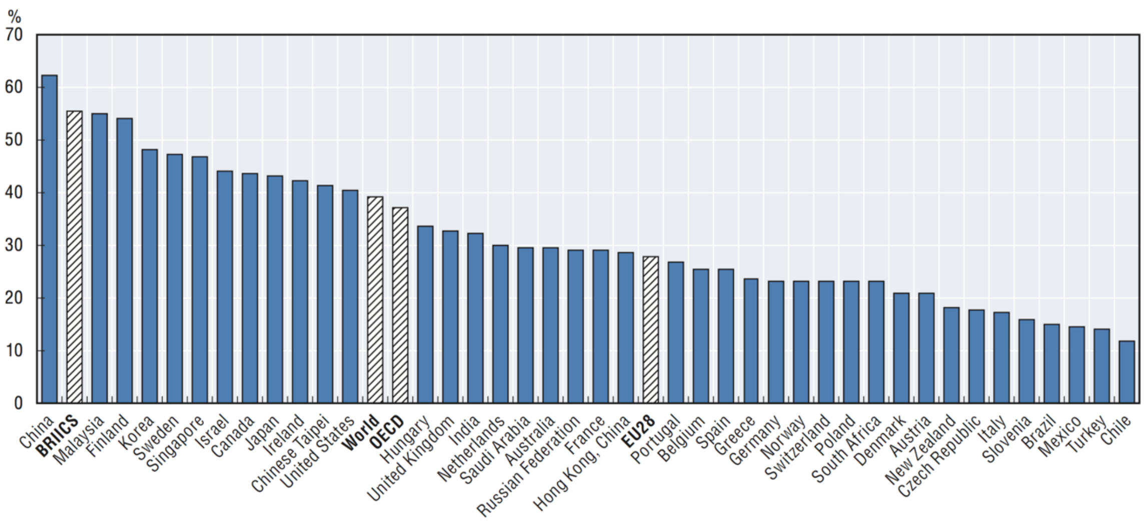

Figure 11: 2010-2012 ICT related patents as a percentage of total PCT patent applications (OECD, 2015a)

2.12 South African healthcare and IoT landscape

South Africa is well developed with much needed infrastructure to take the lead in the IoT in Africa (Ndubuaku & Okereafor, 2015; Okereafor, 2015). However, with the low penetration rate, the country has not been taking full advantage of this opportunity as the penetration is not as high as one would expect. One of the factors affecting this lack of penetration in the Internet might be linked to high levels of poverty and inequality. This is seriously affecting the progression in IoT proliferation.

According to Ndubuaku and Okereafor (2015), who they have listed the following factors as the conditions which could enable IoT to be diffused in Africa: cheaper cost of sensors, cheaper cost of bandwidth, cheaper processing, introduction of Big Data analytics, widespread use of smartphones, ubiquitous wireless network, alternative energy and ultralow power technologies. Some of these conditions have been confirmed by most of the literature as a main enabler for IoT to succeed globally (Chen et al., 2014; Friess & Vermesan, 2015; Manyika et al., 2015; Mukhopadhyay, 2014).

Looking particularly in Africa, South Africa is well positioned to take the lead in IoT (Mukhopadhyay, 2014; OECD, 2015b; Okereafor, 2015; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). However, according to Ndubuaku and Okereafor (2015), for IoT to be successful in South Africa, some of the enabling challenges facing the country would have to also be mitigated. Those include a stable power supply, the high poverty rate, network capacity constraints, illiteracy, low Internet penetration, lack of local content, interoperability and standards, data management, security issues in IoT, and privacy issues in IoT (Ndubuaku & Okereafor, 2015; Okereafor, 2015). However, progress has been made by the IoT Engineering Group at the CSIR Meraka Institute, which is focused on creating a framework allowing for channel agnostic communication between "things" and applications in IoT (Coetzee & Eksteen, 2011). Coetzee and Eksteen (2011) believe that South Africa is well positioned to contribute to IoT by the IoT Engineering Group.

2.12.1 *Healthcare in the Republic of South Africa (RSA)*

The Republic of South Africa (RSA)'s healthcare sector consists of the private and public healthcare sectors. RSA has a concrete National eHealth Strategy. The country also has different healthcare service providers. Though they differ in capacity and capabilities, their common goals are to improve the prevention of poor health; raising standards in the quality, safety and precision of care and medicine; making healthcare delivery more efficient and cost effective; making healthcare more accessible, especially in rural communities, as well as healthcare underserved areas; implementing national healthcare insurance (NHI); and improving from reactive healthcare to context aware healthcare and eHealth solutions (Department of Health South Africa, 2012).

South Africa has also set the eHealth solutions, including a national master patient index with unique identification of patients; workflow information and near real-time healthcare scheduling and dispatch; and remote patient vital monitoring, remote diagnostics and environmental monitoring. This is the basis of the health IoT in RSA (Department of Health South Africa, 2012).

2.12.2 *Internet in South Africa*

Form the literature, we have discovered that the Internet is the backbone of the IoT diffusion. Even if the IoT network was wireless and disjoined, for the devices to intercommunicate, they will still need Internet connectivity (Friess & Vermesan, 2015; Petäjäjärvi et al., 2016).

RSA has a relatively sophisticated ICT sector. There are currently two national licenced fixed-line operators (Telkom and Neotel), five mobile operators (Vodacom, MTN, Cell C, Telkom Mobile and mobile virtual network operator [MVNO], Virgin Mobile), and hundreds of internet service providers (ISPs) and value-added network service providers (VANS) (Gillwald et al., 2012). South Africa has seen the diffusion of the Internet after a wide adoption of the GSM network by the mobile service providers (Asongu, 2015).

One of the requirements for the IoT in healthcare is the low-power network access. The current mobile network access does not meet this requirement (Petäjäjärvi et al., 2016). Therefore, a new network needs to be developed in South Africa, specifically for IoT to meet these requirements. The study could not find literature showing the development of the IoT network in South Africa. However, the LoRa Alliance has reported that several RSA mobile operators have announced the development of LoRaWAN (LoRa Alliance, 2015). LoRa Alliance is an open, non-profit association of members who are collaboratingand sharing experience to drive the success of the LoRa protocol, LoRaWAN, as the open global standard for secure, carrier-grade IoT LPWA connectivity.

2.12.3 *Developments and challenges in RSA healthcare sector*

This section discusses some of the major developments and challenges in the healthcare sector of RSA.

Fair access to healthcare services

According to the NHI documents, it is estimated that the private healthcare sector services approximately 15% of the country population, while the rest, 85%, are serviced by the public healthcare sector (Gray & Vawda, 2016). The expenditure on public and private healthcare is the same. This therefore can be interpreted as giving people in private healthcare better access and facilities, compared to those in public healthcare.

Cost of healthcare

The growth of healthcare costs in RSA has surpassed the inflation rate (Department of Health South Africa, 2012; Gray & Vawda, 2016). According to Statistics RSA, these costs have more than doubled their contribution to household expenditure. The healthcare inflation for services relating to doctors, hospitals, and specifically health insurance, are above inflation (Gray & Vawda, 2016). The RSA government has set a target of reducing the costs of private healthcare (Department of Health South Africa, 2012).

Absence of a national health records system

In RSA, there is still a large number of records which are kept manually (Department of Health South Africa, 2012; Gray & Vawda, 2016). To that extent, the systems which are available, do not communicate with one another. The government does not have a national health record for citizens (Department of Health South Africa, 2012). This has led to a limitation where the records cannot be shared between medical centers and medical practitioners. Because of this limitation, historical information which is required time and again, is always missing and treatment of patients becomes a daily challenge (Department of Health South Africa, 2012).

Healthcare business process management

RSA does not have automated and digitalised business process management in healthcare facilities (Department of Health South Africa, 2012). The business process management involves the process of the life cycle of the patient's interaction with the healthcare facilities from intake to discharge and aftercare, medical provision, check-ups and follow-ups (Department of Health South Africa, 2012). Should this have been available, it would give effect to standardisation across all medical centers, which makes effective and efficient patient interaction with the system.

Sharing of services

Many South Africans in the rural areas are experiencing difficulties in accessing healthcare facilities (Econex, 2013; Mars & Seebregts, 2008). This is due to, amongst other things, widely dispersed population, lack of transport and infrastructure (Econex, 2013; Mars & Seebregts, 2008). These problems have led to initiatives such as using technology to share expertise and knowledge amongst the health care workers across well-resourced and under-resourced areas (Gray & Vawda, 2016; Herselman & Botha, 2016; Mars & Seebregts, 2008). For example, clinics in rural areas can upload X-rays online for the qualified radiologist to view them and offer insight and diagnosis.

National health insurance (NHI)

As a result of the cost disparity challenges in healthcare, the RSA government has implemented a NHI initiative to make quality healthcare affordable for all citizens (Department of Health South Africa, 2015). NHI is also aimed at addressing the quality of public healthcare. The ultimate intention is for the NHI to enter into contract to deliver highly affordable healthcare services to the RSA citizens. This is a long term (14 years) project which was started in 2011. The first five years is dedicated to processing, building and preparing.

2.12.4 *The eHealth strategy in South Africa*

It was found that the government is spending a great deal of money to procure health Information Communication Technology (ICT) and Healthcare Information Systems (HIS), however, it was found that those ICT and HIS systems are not meeting the requirements to support the business processes of the health system (Department of Health South Africa, 2012). This has rendered the healthcare system incapable of adequately producing data and information for management and for monitoring and evaluating the performance of the national health system. These challenges have mainly resulted from the lack of technology regulations and a lack of policy frameworks for all aspects of infrastructure delivery (Gray & Vawda, 2016; Herselman & Botha, 2016; Mars & Seebregts, 2008). To combat this, the government then developed the eHealth strategy which was published in 2012 (Department of Health South Africa, 2012).

The government eHealth strategy is a roadmap which aims at focusing on improving patient information systems. The strategy is centred on the integration and well-functioning national-based information system that is based on scientific standards for interoperability and an architecture that is able to interface with other systems used in the health sector. The information system is intended to address the improvement of the efficiency of clinical care production of the indicators required by the management, and facilitation of patient mobility.

The eHealth strategy attempts to align with and adopt the World Health Organisation's (WHO) definition of eHealth and covers the following areas (quoted directly from the strategy document):

- Electronic health records (enabling sharing of patient data between points of care),
- Routine health management information (e.g. web-based surveillance systems, electronic disease registers, electronic district health information systems),
- Vital registration (the use of computerised systems for registration of death or births),
- Consumer health informatics (access to information on health by healthy individuals or patients),
- Health knowledge management (e.g. best practice guidelines managed and accessed electronically),
- mHealth (e.g. use of mobile devices such as cell-phones to share information or to collect aggregate or patient data),
- Telemedicine (e.g. use of ICTs to provide care at a distance),
- Virtual Healthcare (e.g. teams of professionals working together via ICTs), and
- Health Research (e.g. use of high performance computing to handle large volumes of data)

2.12.5 *Policies and regulations affection RSA healthcare sector*

The major regulations impacting the healthcare sector in RSA include the Promotion of Access to Information Act, Act 2 of 2000, the minimum information security standard (MISS), the National Archives and Record Service of South Africa Act, Act 43 of 1996, and the policy of free and open source software use for South Africa government.

The government has also conceded that policies and regulations need a major shift if the above strategy should succeed (Department of Health South Africa, 2012). For example, Jack and Mars (2013) have done a study on Informed consent for telemedicine in South Africa: A survey of consent practices among healthcare professionals in Durban, KwaZulu-Natal. Amongst other things, they discovered that telemedicine requires an informed consent for a telemedicine consultation, with a copy kept by participating physicians and a copy given to the patient. How this will be achieved in a store-and-forward or telephonic consultation is not clear. In addition, the guidelines require a prior doctor-patient relationship, except in an emergency, and registration of participating doctors with the Health Professions Council of South Africa (HPCSA). They concluded that this would be a major impediment to telemedicine, as it is unlikely that rural patients will have had a prior doctor-patient relationship with the distant doctor being consulted. These are some of the clarifications and regulatory improvements which are necessary for IoT to be diffused in the healthcare sector.

2.13 Conclusion

The conditions for IoT in the healthcare sector vary from the roles that need to be played by the business, inventors, entrepreneurs, investors, government and consumers. Some of these conditions have been identified and discussed.

Though the conditions have been identified, there has not been any study which focuses on the conditions which will allow the IoT in healthcare to be diffused in South Africa. There is actually no study which looked at the diffusion of IoT itself, without applying it to any sector. However, the literature review used different sources to identify the major conditions which have contributed significantly to the diffusion of IoT.

South Africa has its own interesting challenges which need to be mitigated for IoT in healthcare sector to thrive. The gap the study identified is therefore that, all these studies have not been done specifically in the South African landscape. Therefore, this study attempts to discover the major conditions for the diffusion of IoT in health in the South African context.

2.13.1 *Research Question 1:*

What are the main conditions constraining the diffusion of IoT in the healthcare sector of South Africa?

2.13.2 *Research Question 2:*

What are the main factors favouring the diffusion of IoT in healthcare sector of South Africa?

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research paradigm

This study is based on qualitative research methodology. This choice of research methodology is informed by the understanding of the IoT environment that the study derived from the literature review. In essence, the study explores the phenomenon created by the success of IoT in the digital economy, and therefore, for this study, qualitative methodology is most suitable (Collector & Module, 2011; Guba & Lincoln, 1994).

Of particular importance is the fact that there is little to no specific literature on IoT in the South African context. As such, using a quantitative approach would not be fruitful as the structured nature of the quantitative methodology of using tools such as questionnaires, surveys and structured observations would have limitations. Those limitations are mainly centred around the fact that, IoT is a new phenomenon globally, and in the South African context, it is not yet well explored.

The qualitative research method the study used in-depth interviews. This is because the study needed to collect data on the participants' view point about the conditions allowing for IoT to succeed in the digital economy of South Africa. Though there are other methods, such as participant observation and focus groups, they would not have yielded the desired outcome as IoT is an emerging specialised area not yet fully well-known or widely used (Guba & Lincoln, 1994).

This study is a study of social process. It was not anticipated to yield objective unyielding truths that are generalisable beyond the given circumstances. However, this study was congruent with features associated with the interpretivist view.

The interpretivist view fundamentally needs contextualisation (Guba & Lincoln, 1994). This study examined the conditions allowing the IoT to succeed within a particular society at a particular time, and cannot be understood without reference to a particular set of social, economic, political and cultural circumstances. This circumstances therefore would not be well understood by the positivist approach.

A positivist study also requires breaking down of component parts of the study which our study could not able to cater for. The factors allowing for IoT, as derived from the literature review, are inter-dependent and therefore needed an holistic view (Guba & Lincoln, 1982).

The field of IoT in South Africa has received little academic research. Therefore, the study had to sustain an exploratory inquiry. Interpretive research is therefore best suited as it does not approach its subject with an established hypothesis that needs testing (Bowen, 2005).

The purpose of this study was to test if the condition that have allowed IoT to succeed globally, would allow IoT to succeed in South Africa, for which an interpretive approach was particularly well suited. This is because the interpretive approach prioritises the collection of rich data that reflects the context, perspectives and insights of human subjects in a manner that positivists cannot (Creswell, 2003; Guba & Lincoln, 1982).

The interpretivist paradigm accepts the notion that research is value-laden and therefore it is affected by personal and institutional bias (Guba & Lincoln, 1982). It therefore adapts to the reality that the subjects, researchers and readers of this study are likely to have particular views about the desirability, or not, of the success of IoT, and that these views would have an impact on the outcomes of the study.

3.2 Research Design

The study’s research design provided a framework that linked the research paradigm to the methods of collecting, analysing and interpreting data (Denzin & Lincoln, 2000). The study used research questions as a guide to ensuring that the research paradigm did not lend itself to a specific research methodology (Barusch, Gringeri, & George, 2011). An examination of the diffusion of IoT in the healthcare sector of South African would be challenging to accomplish without a qualitative study that draws on the reflections of those individuals most capable of providing insight on these questions (Denzin & Lincoln, 2000).

It has already been suggested that there is little academic literature of the subject in South Africa. This qualitative approach was particularly useful for IoT in South Africa as this allowed the study to be explorative (Creswell, 2003).

The study used semi-structured interviews as the primary method of data collection. For analysis techniques, the study used thematic analysis techniques to identify concepts and themes that assisted in answering the research problem.

Some of the values of the interview method are centred around encouraging the respondent to provide experiences and insights that they consider appropriate to the research question, and therefore are not bound by the preconceptions of the researcher (Curry, Nembhard, & Bradley, 2009). According to Wengraf (2003), a semi-structured interview provides the most effective mechanism of extracting that knowledge (Wengraf, 2003).

3.3 Population and sample

3.3.1 *Population*

The population of the study included key participants in IoT, focusing on the healthcare sector of South Africa. This included vendors/manufactures of IoT devices, service providers involved in IoT, healthcare insurances, public and private healthcare institutions (e.g. hospitals), institutions involved in IoT (and possibly including healthcare) and South African government institutions involved in IoT.

Table 2: Population categories

Category	**Sub-category**	**Qualifying criteria**
Manufactures / Vendors	Manufactures/vendors who are involved in the IoT products and solutions ecosystem.	Manufactures/Vendors who manufacture or sell IoT products and solutions (and possibly including healthcare vertical)
IoT Service Providers	South African enterprises who sell IoT products and solutions	ICT service providers whose products, solutions and services include IoT.
Healthcare institutions	Private and public IoT institutions	Institutions that are concerned about the development of IoT

3.3.2 *Sample and sampling method*

The purpose of the study informed the sampling method with consideration given to design and methodology (Morton-Williams, 1985). Because the study needed the respondents who are capable of contributing to the understanding of the research area, this study therefore used purposive sampling to identify these respondents (Certini et al., 2014).

Since this study sought to understand particular conditions for the diffusion of IoT, the priority of sampling was to establish a suitable quantity of relevant information. It was not aiming to establish whether specific findings about the sample group could be generalised to the population as a whole. This is rather an objective that would be more effectively achieved with random sampling (Lincoln & Guba, 1985).

Because the purpose of the research was to collect sufficient information to adequately answer the questions, the optimum size of the sample wias guided by the extent to which new information was forthcoming from interviewees (Lincoln & Guba, 1985). Redundancy (also described as data saturation) was therefore a central consideration when determining sample size. Simultaneously, the study tried not to make it be too large to limit the ability of the researcher to achieve sufficient depth and richness of data (Onwuegbuzie & Leech, 2007). This meant that the size and composition of the sample was ultimately contingent on the extent to which the interviews uncovered novel information and insights as they progressed (Onwuegbuzie & Leech, 2007).

A list of potential interviewees was compiled with the intention of providing a broad cross-section of views and perspectives. If required, further interviews would have been identified using the snowball method, subsequent to interviews with other participants (Biernacki & Waldorf, 1981).

Lists of institutions interviewed is attached in Appendix B.

3.4 The research instrument

This study used an interview guide as the basis for interviews conducted by the researcher. Since the study sought information and understanding, not representivity, there was little value in using a standard and fixed set of questions for all interviews (Wengraf, 2003). It sets out a few main questions that related to the different elements of the research problem. They are ordered to achieve a logical flow, with a few points that could assist the researcher in formulating follow-up questions (Rubin & Rubin, 2005). This flow was designed to assist in ensuring the discussion stayed focused while allowing the interviewees' specific interests and views to emerge.

Even though the people selected for interviews were well versed in the subject, the interview guide used terminology and concepts with which the interviewees would be familiar. Rubin and Rubin (2005) caution against using the research question as one of the questions in the interview, arguing that interviewees are unlikely to relate to its academic tone.

The questions in the interview guide needed to be appropriate to the interviewee. As such, different interview guides were developed for the different categories of respondents. This recognised that each interviewee had a different view within the area, different priorities and different interpretation.

The interview guide is attached as Appendix C.

3.5 Procedure for data collection

Mostly, data was collected through face-to-face interviews with respondents. This approach was selected as preferred over telephonic or electronic interviews. This is because the manner of response, which include the words being used, tone of voice and body language, provide further insight into the content of the response (Bluhm, Harman, Lee, & Mitchell, 2011). In three instances, logistical challenges precluded face-to-face interviews. In these cases, telephonic interviews were used. All but 16 of the face-to-face interviews took place at the respondents' offices. Being comfortable in their environment, helped to provide meaningful context to their experience and perspective (Bluhm et al., 2011).

To be more accurate and accountable, all interviews were audio-recorded. According to Lincoln and Guba (1985), this might discourage the respondent to be more open. Given the nature of this study, profiles of the respondents, the anonymity that the researcher promised interviewees and the lack of controversy attached to the subject, this was of no significance of significance.

As the interviews were audio-recorded, it contributed to accurate reporting and assisted in detailed analysis and accountability (Bryman, 2004). The audio records were then transcribed by the researcher. These transcripts formed the basis of the data analysis. The study ensured anonymity by using codes and categories instead of using the respondents' names (e.g. IoT SP A) All the coded sections in the transcripts have been numbered sequentially. In the report, verbatim quotes are referenced according to the transcript code (e.g. Vendor A).

3.6 Data analysis and interpretation

The study used thematic content analysis to recognise and analyse themes within the interview transcripts. This is achieved by generating codes that describe elements of the data considered by the researcher to be relevant to the research topic (Braun & Clarke, 2006). The choice of codes is a subjective process, in this instance determined by the reading of the data (referred to as inductive coding) rather than using pre-existing theory (referred to as theoretical coding) (Braun & Clarke, 2006). This type of code generation is appropriate to a study of this nature, which is largely exploratory (Braun & Clarke, 2006).

The process of coding is iterative, requiring several re-readings of the data to establish if existing codes are appropriately defined, and make any adjustments necessary to improve the categorisation of the information (Braun & Clarke, 2006).

After the interviews were transcribed, they were coded. This codes were then arranged into candidate themes that reflected broader patterns of meaning within the text (Braun & Clarke, 2006). Then the coded sections were reviewed and each assigned to one or more of the following categories:

- Constraint, which describes a condition that potentially or actually constrains the diffusion of IoT in the healthcare sector of South Africa.
- Enabler, which describes a factor that potentially or actually enables the diffusion of IoT in the healthcare sector of South Africa.
- Improving, which describes a condition that show the improving conditions for the diffusion of IoT in the healthcare sector of South Africa.

Once categorised, the codes were then arranged into revised themes. These themes are shown in the thematic map. This formed part of the findings contained in the next chapter.

An illustration of the thematic map is attached as Appendix D.

The process of interpretation is conceptually distinct from analysis. While analysis involves the reduction of the data into categories and themes, interpretation involves an explanation of the significance of those themes, and how they can contribute to a finding on the research question (Patton, 1987). The interpretation process must therefore extend beyond description to capturing the researcher's understanding of the meaning of the data. The interpretation is written up as a narrative discussion of the key findings, on which are based the conclusions and recommendations.

3.7 Limitations of the study

Creswell (2003) believes that by definition, the study that takes place within an interpretive paradigm is shaped by the subjective meanings established by the researcher. As this research is of interpretive paradigm, it is therefore affected by the capacity of the researcher for intellectual comprehension, the respondents' values, prejudice and preconceptions. This however was mitigated by the clarity of the context as it limited the perceptions of undue influence on the authenticity of the findings (Barusch et al., 2011).

The exploratory nature of this study meant that the form, scale and significance of outcomes is less certain than would be the case in quantitative research (Guba, 1981). This in turn required greater adaptability by the researcher and provision for flexibility within the research design (Guba, 1981).

The proximity of the researcher to the research participants increases ethical concerns, either because the respondent may be affected in some way as a result of their interaction with the researcher, or because the researcher may inadvertently influence their responses (Bowen, 2005). However, given the profile of the proposed respondents, and hence the probable power relations between respondent and researcher, the study considered this risk minimal.

Other ethical considerations relate to confidentiality and anonymity (Christians, 2005). Respondents were offered confidentiality and anonymity as attached in Appendix C. Each interviewee was provided with an information sheet prior to the interview, which outlined the purpose of the study and the conditions under which any information they provided would be used. It also indicated that participation in the study was voluntary and that they may withdraw from the study at any time. This sought to ensure that interviewees' consent to participate in the study was informed (Lincoln & Guba, 1985).

There were particular time and resource constraints on this study, which meant the choice of respondents was limited to specific geographical locations (in this case, to Gauteng). The time restrictions for the completion of this research report limited the number of interviews that could be conducted, especially since analysis of qualitative data can be time consuming (Morton-Williams, 1985). The possible impact of these constraints on the quality or value of the research were regularly assessed as the study progressed, and necessary adjustments were made.

Since there are relatively few participants in this sector, the possibility that several may be unavailable or unwilling to be interviewed would have a significant impact on the breadth and richness of the data collected (Lincoln & Guba, 1985).

The interview as a form of data collection has some limitations. Information can be distorted, both by the views of the interviewee and the presence of the interviewer (Rubin & Rubin, 2005; Wengraf, 2003). Due to different respondents' presentation styles and ability, it is possible for certain views to gain greater credence (Creswell, 2003). One of the ways this can be minimised is through triangulation of types of sources (Barusch et al., 2011).

Using thematic content analysis has inherent challenges (Weber, 1990). There is a risk that in the reduction of data into categories and themes, certain critical elements may be lost or misinterpreted (Weber, 1990). This danger is always present in a qualitative approach, however, it can be minimised by making analysis a reflective and iterative process (Weber, 1990).

3.8 Validity and reliability

3.8.1 *External validity*

External validity can be likened to transferability (Guba, 1981). In essence, it is about the extent to which findings in one setting can be applied in other settings (Guba, 1981). Generally, qualitative research has poor transferability due to its context-specific nature (Bowen, 2005).

Techniques that can be used to establish the likelihood of transferability exist. They require a full understanding of the respective context of the research report (Creswell & Miller, 2000). This can include the careful use of quotes from interviews and intense descriptions of interview settings (Barusch et al., 2011).

3.8.2 *Internal validity*

Internal validity is mostly akin to credibility, which the extent to which the interpretation in a study accurately reflects the data (Guba, 1981). This study used triangulation as a strategy to reinforce credibility (Barusch et al., 2011). The triangulation strategy involves sources of information from a range of different respondents with different perspectives, in order to deepen the understanding of the topic (Barusch et al., 2011). The study achieved triangulation by conducting interviews with stakeholders from three different group categories, being entrepreneurs, business and government.

Another strategy which the study used to enhance credibility is disconfirming evidence (Creswell & Miller, 2000). The strategy involves a deliberate effort to find information that contradicts the main theses emerging from data analysis (Creswell & Miller, 2000). This analysis is intended to enforce a greater confidence to the validity of the ultimate results' interpretation by ensuring that the existing contradiction forces the researcher to re-examine his analysis (Pope & Mays, 1995).

3.8.3 *Reliability*

In qualitative research, stability (also known as dependability) is the element of reliability that receives the utmost attention (Bowen, 2005). This refers to the likelihood of achieving similar research outcomes if the study were to be replicated at another time with similar respondents in a similar setting (Guba, 1981).

The study increased the likelihood of reliability by ensuring that each step of the research process was precisely and meticulously recorded (Pope & Mays, 1995). The study also used an audit trail of all research activities and decisions which could be used by any external auditor to establish the reliability of the findings (Creswell & Miller, 2000). The documents that served as an audit trail are attached to the appendix.

CHAPTER 4. PRESENTATION OF RESULTS

4.1 Introduction

This chapter outlines the main findings of the research. It begins with a profile of the respondents and an overview of the IoT in the healthcare sector of South Africa. This is followed by findings with respect to the two research questions, describing, firstly, the main conditions that constrain the diffusion of IoT in the healthcare, and, secondly, the main conditions allowing for the diffusion of IoT in the healthcare sector of South Africa. This is followed by findings on factors that could contribute to the improvement of conditions allowing for the diffusion of IoT in the healthcare sector of South Africa. The chapter concludes with a summary of the findings.

4.2 Demographic profile of respondents

These findings are drawn from 19 interviews with respondents from 18 organisations. Between them they represent different levels of the diffusion of IoT in the healthcare sector of South Africa. The institutions represent both private and public healthcare (hospitals and clinics), governmental organisations like state owned firms and non-governmental organisations like health insurance firms. The vendors are firms that manufacture IoT related products like sensors, networking equipment, etc. The IoT service providers include those firms that provide IoT solutions. In most of the cases, these IoT services providers are the bridge between the clients who need the IoT solutions and the vendors who manufacture the products. From these different perspectives, they have provided a composite overview of the landscape of IoT in healthcare.

The respondents share a similar view regarding the IoT landscape in South Africa. Also, of importance, all the respondents' organisations share a common goal of improving patients' quality of life and experience. This is amidst their different legal identity, mission and formations. Some organisations are state owned and therefore not for profit, whereas other organisations interviewed are commercial organisations.

There is significant diversity in the organisations interviewed for this study. Those interviewed differ significantly with respect to their activities, scale, structure, vision and mission.

4.3 Overview of IoT in the healthcare sector of South Africa

South African healthcare services are divided into two, being private and public healthcare. One respondent summarised the historical background of the South Africa public healthcare as below:

> *"So, I think it is useful to take one step back and talk about technology in healthcare in general. Obviously, the health space is a good space in terms to technology from diagnostic devices that you get to the systems that you find in our clinics and hospitals. More recently but not so recent anymore, there emerged an idea of eHealth. Essentially, it is anything to do with technology in healthcare. A lot of technology is developed by mainly the private sector to be used in both the private and public healthcare sector. One of the problems we had in this country about 10 years ago is that, there was a lot of money which was spent on the acquisition of technology and systems like healthcare record systems. Towards the year 2009, the government realised that they are spending lot of money into these technologies and they were not getting any value from it. We did an analysis and realised that there were about 42 systems deployed around the country. None of these systems were sharing the information. Fragmentation of those systems became a big problem because if you were to move from one medical facility to another, that facility does not have your health record. Even within the private hospitals themselves, you would not find any of your record. So, at that stage, the*

National Health Council decided to put a moratorium on spending in healthcare system until the fragmentation problem was solved. This is where the National eHealth Strategy emerged. One of the things National Health was to deal with is fragmentation and interoperability. Now, a lot of the work we do is in the area of fragmentation and interoperability of the eHealth systems. The first thing we said was, if the systems were to communicate to one another and share information, there would have to be a standard to be used. And then we developed the Health Normative Standard Framework for Interoperability in eHealth in South Africa, which was gazetted in 2014." Institution C

While the private healthcare has intensified the regulatory environment against their operations, the public healthcare in South Africa is still struggling with the basic things. This situation in the public healthcare has led to manual prevalence with lack of or no automation.

"If you are looking at the implementation of ICTs in health, if I had to choose a few key challenges, one of them is related to the reach of ICT at the moment. Most of the public clinics at the moment, they do not have computers and Internet access. The Minister of Health termed it lack of automation. So, most of the things happening here are paper based. So, you can imagine in an environment like that, it is difficult to bring about innovation as we are still battling with the basics. Sometimes the nurses and doctors have to fill up a lot of paper work which takes them time. They are then sent to someone who needs to capture this information into the system of some sort which at times then there are mistakes or file them. While other public healthcare centers (hospitals and clinics) have unstable Internet connectivity, some do not have any Internet connectivity. Some of the healthcare centres do not have the computer to record any information. This is due partly to lack of skills in the

> *healthcare centers and lack of network connectivity."* Institution C

Moving now to the private healthcare, they have made significant progress in term of the implementation of IoT. One of the respondents gave an overview below:

> *"Five years ago, people used to travel overseas to do prosthetic surgeries now they can do it in our own country, so there is a couple of science that has brought up the robots and our surgeons are actually being trained quite there. Even with the hot stuff type of thing South Africa is actually leaders in certain areas of getting into the hard part of through a little capita, little blood vessel all the way up into the heart and actually performing the little surgical procedures in the heart and even replacing valves. The other thing we have is digital theatres, in terms of our theatres and stuff like that we have a lot of what we call digital theatres where the doctors when they are operating they are actually watching operations on a computer screen, so they can actually work on a computer screen and sometimes they work through little 3D surgeries, so they can do work on your stomach inside through a little hole and actually operate It and do the whole operation with a tiny puncture wound. They push the equipment through the skin and the equipment and do things like burning the blood vessels, cutting and shaping and performing your surgery and after they have been able to complete the surgery like that you are left with two little puncture wounds and minimum invasive back to work quickly. Some of these are now in 3D you sitting there watching it on your screen, you can see it while you operating."* Institution D

Though the private healthcare institutions have made greater progress compared to the public healthcare, they also have a fair share of their challenges.

"We actually have made very big strides from that point up till now in terms of automation and those type of things. I would actually say if you are looking at the healthcare space you have more or less got two competing issues in the health space - cost and efficiency. So, you actually very squeezed in the sense because you've got these competing things, I mean how do you lower the costs, improve the efficiencies and at the same time get the quality up because quality costs money."
Institution C

Even though the private healthcare institutions were faced with this challenge, they managed to turn around and are now in the trajectory to fix it.

Amongst the healthcare centres, public or private, there was no sharing of patients' information. Amongst other factors, this is due mainly by regulations.

"The second biggest challenge is related to the fact that, even if there are systems, there is no sharing of information. This is because the systems were never designed to share that information. For example, if you are the CEO of the hospital, and you procure the healthcare system, there is no requirement for you to share any information with any other hospital. In fact, you would be scared to do that because of the patient confidentiality issues and all related privacy issues. There are strict policies and legislation around the sharing of information. Who get to access what information, under what circumstances, how do they access it, and what can they use the information for." Institution C

The impact of this is high as, for example, when the patient is transferred from the public healthcare center to the private healthcare center (or vice versa), they cannot take their records with them or their records be made readily available. As such, they are sometimes subjected to the same healthcare tests and analysis that the other healthcare centers might already have done.

> *"Very often patients have x-rays in public and then they will go to private hospital because they are not getting the attention they need and they will have to redo those x-rays because public hospitals wont shares them. In private you pay for your x-rays and you get then given to you, so you can go with them wherever you go, so if you change doctors or have to see a different doctor you can actually take your x-rays and stuff with you."* Institution D

All organisations interviewed have a project, product or they are using a certain IoT solution. However, the study has found that specifically in the healthcare sector, there is little to no activity in IoT. This is mainly due to factors such as the highly regulated environment, lack of entrepreneurship drive in South Africa, standardisation which drives interoperability, available network for IoT devices to connect, available IoT solutions, privacy and security, high cost of data, socio-economic factors, lack of transition into IoT in the healthcare sector and lack of skills. However, of all those reasons, the major factor for the constraints of IoT diffusion in IoT was found to be regulations in healthcare.

Against the constraints the study discovered, there was a clear enabling environment for IoT in healthcare. Some of the enabling environment includes the proliferation of the smart phones, readily available Internet access (this is not the IoT network, but the Internet), the cloud infrastructure necessary for IoT, and innovation in the South African IoT landscape.

> *"Today your mobile phone in the rest of Africa can do your banking. We have developed solutions to put your entire health information in your smart device"* Vendor B

Some of the organisations have already taken advantage of the enabled environment and developed IoT solutions in healthcare sector. All of these organisations' vision is to move healthcare closer to the patient's home using IoT as a transition to a better health.

> *"Based on the trends, healthcare is moving from the hospital to the community, people's houses. The most important thing is*

that, this people need to be connected and vital signs need to be collected on those people. Some of the solutions already developed and working include the medical box, personal health and fitness solutions, the creation of platforms for IoT developers to develop the solutions against the lack of standardisation, and the use of IoT mainly in the private hospitals. Institution C

4.4 Main conditions constraining the diffusion of IoT in the healthcare sector of South Africa: research question 1

4.4.1 *IoT diffusion against the highly regulated environment*

Most of the interviewees saw the South African regulatory environment as one of the main factors constraining the diffusion of IoT in the healthcare of South Africa.

One of the respondent summarised the views of most of the respondents below:

> *"South African healthcare is highly regulated. Even telemedicine, it hasn't taken off in South Africa because of the regulations associated with it. For example, if a patient comes to the doctor, the doctor can phone one of his colleagues as a doctor to get an advice and use that advice to diagnose the patient. However, the patient cannot call the doctor to get the diagnoses over the phone – it has to be a face to face appoint. An example is hellodoctor, which is attempting to provide the healthcare service over the phone. They spend few years in the court trying to win this over and they failed."* Institution C

According to one respondent, the South African healthcare regulations were well intended. However, in the agile environment where technology is moving into healthcare, there is a need to review the regulations.

> *"Though the regulations are high, they were well intended. Imagine the HIV status of a patient being exposed to the public, there will be a lot of reputations ranging from the stigma that we still see in South Africa, to some employers being sceptical about employing her on the basis that she is HIV positive"*
> Vendor D

The impact these regulations have in the IoT for healthcare sector is the major constraint to the diffusion of IoT in healthcare. To give a perspective, one of the private healthcare respondents described the situation as follows.

> *"One of the difficulties and I don't know if you are aware of this here in the South African health care, the way our industry is structured in private health care is that we are not legally permitted to employ doctors, we as a hospital do not employ doctors by law. So that is what a lot of people do not actually understand. Now you will actually understand when I tell you when you get your bill from a private hospital. You will get your bill from the hospital, from the doctor, from the anaesthetist, from the surgeon, from the pathology and lab that has done your blood and the extra doctor will bill you separately. So, every doctor is a separate business and the hospital business is actually to do two things, to provide with the accommodation, the nursing care, technology and equipment but we do not bring patients into the hospital and do not discharge them from the hospital. So, the only person who can bring a person into the hospital and discharge a person is doctor, he is a separate business man and he runs his separate business. We are not allowed to be in partnership, we cannot share anything. I cannot pay him to bring patients into the hospital. It must be that he wants to use that hospital."* Institution D

As such, the private healthcare does not actually have any control over the patient, only the doctors who admit them does.

> *"That is why you cannot instruct a doctor, you cannot tell the doctor you need to do this or that or you need to discharge that patient. That is why sometimes you find that private hospital care, people say that private hospitals are to be blamed but in reality, we do not actually have the control of how long a patient stays in the hospital, what happens to them in hospital is determined by the specialist."* Institution D.

Because of the private hospitals not having control over patients, this has led to the lack of technology adoption in the private healthcare.

> *"This has actually been one of the biggest reasons why now there have been delays in pushing in new technology because you've got to sell it to a person who is not part of your system, who does not need to be part of your system and may not even want to be part of that particular system. So, if you just brought in an electronic health good you might get half of the doctors telling that they are not interested in using that electronic health good, they might say they are too old and do not want to learn, they will carry on using paper, or you might have a situation where guys tell you that we know we got a better system in our rooms and we do not want to use your system."* Institution D

One of the respondents saw the eHealth strategy as one of the solutions the government is using to enhance the regulations in South African healthcare for technology. However, the development process of this regulation and its associated implementation is frustrating the diffusion of IoT in healthcare.

> *"Because the government is developing the strategy for eHealth, they will have to develop the associated regulatory framework that will make the eHealth succeed"* Institution C

Some of the organisations have sought some solutions amidst all the challenges. For example, the South African healthcare regulation require that the patient needs to provide permission for any medical practitioner to access the information. Because the organisations, such as healthcare insurance companies, own the patients' data and have access to a network of medical practitioners, they have developed a system where they collect all the data and store it in their cloud network. Should the patient agree for the medical practitioner to see the data, all the data for that patient is made available to that medical practitioner.

> *"You give the doctor permission to access your patient profile so when he logs on with your permission then all of the information that we have on you is given to him. Clinical history, blood test results etc. To get your clinical results from your other doctors, because we have the data and technology, we store it all and we allow you to determine which doctor you would like to share it with*" Institution E

Also, National Health Insurance (NHI) will be coming with a new policy framework which will advance the eHealth policy framework. This is important for IoT in healthcare diffusion as NHI looks more into prevention than cure therefore, it is looking at cost effective prevention models such as those brought forth by IoT. Most respondents agree that one of the major benefits of IoT is to bring healthcare closer to the homes than in the healthcare centre. As such, for this to happen, this people will have to be connected and vital signs be collected through the network.

> *"NHI is useful because it set the policy context for South Africa. Right now, it is the most important policy context in South Africa."* Institution C

4.4.2 *Lack of IoT standardisation and therefore interoperability*

Almost all respondents agreed that standardisation has an impact on the diffusion of IoT in the healthcare, and this standardisation leads to lack of interoperability. This then leads to different vendor solutions not being able to communicate and interoperate.

> *"IoT is still an emerging technology with lack of standards. Because of that, we have resorted in developing our own platform to enable our IoT products and solutions"* Vendor E

Therefore, some organisations have developed IoT solutions which now operate in isolation without interoperability. This was done based on the specific customer needs and requirements. Therefore, these solutions are highly customised and might not work for all customers. An example of such a solution was given by one of the respondents as being the patients' healthcare records software developed to be used in public clinics. Because of lack of standardisation, this software might not be used in different environments.

> *"Because of the lack of standards, we can build our solution ground up. We also bought an organisation to harness some of the IoT solutions they already had. Our solutions are completely isolated"* Institution E

It was noted by a few respondents that this situation can be eliminated if the South African government and private organisations start being part of the bigger IoT community which makes standardisation decisions. The respondent mentioned that South Africa has minimal to no active role in the global shaping of IoT as an emerging technology.

> *"There are lot of conversations that are happening around the globe which are trying to bring about the standardisation. Some of the challenges we have are time and resources like money to be involved. So, we end up being the receiver of those standards instead of influencing these standards. This is not ideal. If we really serious about this IoT in healthcare"* Institution C

4.4.3 *Lack of availability IoT network*

The IoT network has specific requirements. One of the respondents summarised the requirements of IoT network below:

> *"Though we roll out LTE network, which covers 99.8% of the areas in SA, the main thing is the lower power and the battery requirements for IoT devices. Devices need to last for four years verses the power that you need on your LTE device. For example, if you charge your LTE device, it only lasts for a day. So, you don't want to, for example, if you have meters in a ground like one meter in the ground, you can't do that. The quality of the reception is better on the narrow band as the battery can last about five to six years"* IoT SP G

It is this IoT network which will make the devices to be able to communicate. Most of the respondents agree that the Internet in South Africa has developed, however, the development and deployment of an IoT network is still lacking. This was partially due to the facts that IoT is still an emerging technology.

> *"We believe that 20% of South African's suffer from blood pressure and diabetes. Less than 1% from that population is being monitored today. The challenge with that is the technology today. We have advanced so much right now we shouldn't be this disparity of 20% suffering from this chronic disease and only one being monitored. In fact, these are lifestyle diseases that can be treated through a lifestyle change but my people perish from lack of understanding. The people don't understand, the people don't know, people are dying from that ignorance."* Vendor B

However, a few of the respondents noted that even though IoT is still new, the lack of development and availability of the IoT network is partially due to ICASA, the spectrum regulator, not providing the spectrum for organisations to deploy the IoT network.

> *"The government is slow in providing us with the spectrum. This would allow us to deploy the IoT network faster."* IoT SP G

As a solution to the spectrum challenge, some of the mobile operators and other service providers have started the development and deployment of LoRaWAN because it uses their existing infrastructure and spectrum.

> *"We have built a LoRaWAN network for IoT to make IoT more affordable. The network is already operational with lots of customers in it. It is only in major metros right now." IoT SP C*

Another IoT service provider are also developing the same network:

> *"We have invested in building the Narrow Band IoT (which is LoRaWAN) laboratory. Our strategy is to roll out this LoRaWAN in metro areas to provide machine to machine communication and commercialise IoT."* IoT SP G

Even though most of the organisations are citing spectrum as one of the constraining factors, the South African regulator believes that with the developments which are happening within their organisations, the solution is near.

> *"We are busy with the 5G forum which is about interconnectivity of the devices. This will enhance the IoT policy. This will give ultra-bandwidth to the end devices. This includes working hard on the spectrum to allocate to the service providers."* Institution F

4.4.4 *Lack of available cost effective IoT solutions*

The IoT solutions comprise devices which are rarely available in the healthcare sector. These devices include the sensors and the IoT network. Most of the respondents agreed that we do not have readily available IoT solutions for healthcare sector today. Below is a summarised view from one of the respondents:

> *"All of our sensors are imported from overseas. We could not find the required sensors for the customer solution in South Africa." IoT SP F*

Apart from interoperability as one the reasons for lack of IoT solutions, some of the respondents have cited the fact that the South African market is not yet ready for the IoT solutions in the healthcare sector. Some of the reasons include the lack of uptake in the solution due to the regulatory environment.

In the private healthcare sector, they are faced with the challenge of quality against rising costs. The challenge is that the cost of the IoT equipment in the healthcare is expensive. One of the reasons for them being expensive stated below.

> *"One of the things with costs is that, firstly there quite a lot of equipment we buy comes from oversees. So, if you want to be at the fore front of health care technology you buy your equipment, some machines cost us up to twenty Million rand per machine. You know so if you are building a CAT lab, the equipment alone is twenty Million rand, you know you can build a whether you buying these robots or to do prosthetic surgery those robots where twenty Million each when they were actually introduced into the country two to three years ago."* Institution D

The private healthcare also has a challenge that they have to stay up-to-date with the technology since should they not, the doctors leave for overseas where things are much more advanced. Since they do not want to lose them, they have to keep up with the technology.

> *"One has to stay up with the technology because if our doctors are not up-to-date with what is happening in the world around the latest techniques and technologies they also then start leaving for overseas because they want to be using technology that everyone used ten years ago."* Institution D

The challenge then is, how do they guaranteed return on investment against all these quality and cost challenges.

> *"So, what do you do? Do you first bring in all these, you know take a chance and buy all these sophisticated systems and hope that you going to get those patients? If you get the patients first and do not have the systems you actually cannot deliver the health care efficiently. So, it is very much in a rock and hard place sometimes with those types of systems."*
> Institution D

The machines are expensive because of the quality they bring. One of the respondents summarised it as saying:

> *"We do not see quality as nice to have, quality in the health care is mandatory, it is entry level and what you seeing now is that people are starting to, like in America, put quality indicators onto the website. So, patients now can go into the website and start looking at this hospital has these outcomes and this hospital has those outcomes and they can start making purchasing decisions about where they want to go depending on which hospital has a better outcome on the Internet."*
> *Institution D*

4.4.5 *Privacy and security vulnerabilities*

All respondents agreed that one of the critical conditions for IoT to be diffused is the patients' privacy and the system security. Almost all of the respondents agreed that should one of the privacy or security issues emerge in the healthcare, it will be the end of IoT in healthcare.

> *"Security and privacy are absolutely critical. Unauthorised patient information can be life threatening and can be used in those methods such as committing murder for instance. If*

somebody knows what you are allergic to, that person would know how to make you vulnerable. Vendor A

It is some of this privacy and security issues which have not yet been solved globally that has led to the South African government to implement the high level of regulations.

"Look, security and interoperability are currently unsolved internationally." Institution A

Privacy and security therefore constrain the diffusion of IoT because of the need for balance between the diffusion of IoT in healthcare, and the patients' privacy. One of the respondents summarised the view of many by saying:

"There is a huge need for clear policy and enforcement around the policy. In the healthcare sector, there are currently lots of breaches in confident data. Education needed in the health care sector about the compliance of such regulations and the breaches of the securities therefore. Government need to create awareness, regulations and enforcement. These policies without enforcement will become useless. I don't think it is a deal breaker, but it is necessary. Even the first world countries are having challenges with this. It slows down the adopt curve though, and complicates the implementation as we need lot of stakeholders' approval for this to take off. The buy-in becomes extremely challenging as a result. Any system is as strong as its weakest link" IoT SP B

Respondents agreed that systems exploits are unlimited, ranging from hackers' attacks, denial of service attacks, malware infection, botnet hijacks, and errors in system codes. For IoT to be diffused in healthcare, there is a need for standards which will address these security challenges.

The study found that the privacy of the patients is paramount. All respondents agreed that there is a need for privacy. That privacy of patients range from the need to safeguard the personal identification information, personal healthcare records, and payment card information. The study has found that this is one of the conditions that need to be resolved for IoT to be diffused.

A few of the respondents agreed that the impact of this privacy and security in the diffusion of IoT in healthcare is high. It ranges from the death of the patients to patients having lost their privacy due to systems being hacked, information stolen and published unauthorised.

> *"The biggest part of this, especially in the healthcare sector is securing patient information. Not only securing information but also securing the communication from the device to the database that stores the information as well as the terminal where the doctor accesses this information. We need end to end security from the device to the terminal. Security is the biggest pillar to success."* Vendor A

Some of the respondents see this as an opportunity more than a challenge.

> *"If we can protect your money using the current security infrastructure that is there, we most likely can protect your data. So, we believe that the competences are advanced enough to be able to deliver that."* Vendor B

However, there are current initiatives aiming at reviewing the current privacy and security in order to align them with the global developments in IoT for healthcare which will eventually make IoT in healthcare diffused.

> *In regard to privacy and security, we have made some recommendations to the government. We looked at what some of the other countries are doing, but we have not been to a point where the policies are published. So, it is still in progress.* Institution C

One of the respondents had a complete different view to the privacy and security.

> *"I don't have any problem with any privacy because we are living in the social media reality where anyone can know anything about anyone anytime."* Institution B

4.4.6 *High cost of data*

With the proliferation of the IoT devices, the study also found that the cost of data is high. One of the respondents captured the view below:

> *"One of the limiting pieces for us to adopt IoT is our infrastructure. We definitely do not have infrastructure to adopt these types of solutions. The data is very expensive in South Africa and not easily available especially in rural areas. If you find it, the speed is not fast, and if you find it faster, it is fairly expensive. That seems to be a factor that not enabling but rather limiting the adoption of something like IoT."* Vendor A

Wireless spectrum is also costly, and carriers have different needs for it. One of the respondents said that, based on those challenges, IoT devices that pay less will never get network access priority over cell phones which pay high amounts per month. Therefore, the opportunity cost of supporting IoT devices is too high.

> *"The price of data certainly needs to come down. For all devices to get similar priority over the carrier network, the prices should come down drastically. Else the carrier will prioritise high paying subscribers neglecting the IoT data and therefore compromising the real time nature of IoT"* Vendor E

In South Africa, there have been several initiatives to bring down the price of data. These initiatives are still on-going. The study found that it is very important for the cost of data to come down for the benefit of the diffusion of IoT.

As a solution to these challenges, some of the wireless carriers are building their own IoT network dedicated to the connectivity of many devices. This will be a dedicated IoT network (LoRaWAN) which will not be sharing the resources with other wireless devices like cell phones.

4.4.7 *Socio-economic factors*

The study found that the South African socio-economic factors such as high poverty prevalence, inequality and unemployment are constraining the diffusion of IoT in healthcare. The economic factors, such as recession, also play a role in the diffusion of IoT.

> *"One of the factors I am seeing is the economic recession which has an impact on the South African investment sustainability. For example, when people are poor without employment, how would they buy the IoT solutions then? If they don't buy them, how will IoT be diffused?"* Vendor C

These social-economic factors lead to some of the IoT healthcare initiatives not being financially sustainable. This view was captured by one of the respondents below.

> *"So, the other challenge is sustainability – funding issues. A typical example is MomConnect. Essentially, it is a mobile health service where pregnant women register themselves in this service. They are registered at the clinic. Using the service, they are send SMS messages throughout the pregnancy. They also use the momconnent to complement the clinic or raise complaints. This goes back to the department and they try to fix the system. Momconnect is close to 800 000 women registered making it one of the most successful program. It took several government and private stakeholders. And as you can imagine, as the SMSes cost money, sustaining such a project on the ongoing basis need a sustainable business model."* Institution C

4.4.8 *Low levels of IoT entrepreneurial activities (localisation)*

South Africa's low level of IoT entrepreneurial drive has an impact in the diffusion of IoT in healthcare. According to the respondent:

“Unlike other countries in America and Europe where you find lot of available investors willing to invest in new start-ups, we do not have that in South Africa.” Vendor D

This entrepreneurial activity involves the ongoing research and development of IoT solutions in healthcare, localisation of the IoT solutions as currently most of the products and solutions are imported, and the high level of entry into IoT products and development by many South African organisations. One of the respondents summarised the situation as saying:

“South African government has got a very big drive towards localisation of technology. So, we need to have our own capabilities, technologies, in a way try to keep the money inside the country vs the country is paying in dollars on some commercial companies, where the money just go out.” Institution A

One of the factors for low level of entrepreneurship in South Africa is lack of governmental involvement in funding IoT initiatives.

“It was tough to get funding for a new technology. Government organisation not too supportive. No incentives from the government.” IoT SP C

The impact of the lack of entrepreneurial activities has been witnessed as the cost of the IoT solutions are always increasing as most solutions are imported. As a result, this will have an impact on the diffusion of IoT in the healthcare sector of South Africa.

According to the respondent, the government could take a leading role in ensuring that the IoT entrepreneurial landscape in South Africa is thriving. However, currently this is not visible, if it does exist.

However, one of the respondents argued that the lack of entrepreneurship drive is due to lack of IoT skills. This is due to lack of training platforms.

“You need to build capabilities first. That implies that you need to have courses at universities that are close to IoT where students are able to build their own IoT based companies, go into research organisation or bring solutions. So, at academia level it could help already. At manufacturing level, we need our own local manufacturing industry to create our own devices that can track and trace person’s blood pressure without going to the clinic every week for instance. So, we need to find ways to enable local manufacturing industry taking it up if the solution is enough, we need to host it somewhere. Again, that’s create an opportunity for somebody. You have got lots of hosting companies. Building niche solutions specifically for South Africa ensuring that the competition is locked out, thereby creating a competitive advantage. An international guy might come, it will take him few months to understand the real meaning, context, and needs. Somebody to develop that solution. There we have a competitive edge and that’s where you can drive innovation. If we are able to address some of these solutions. Connectivity need to be improved, more especially in the unserved areas. For example, narrow band IoT connectivity for the rural areas. Security capabilities for IoT. Raise awareness and processes to address security.” Institution A

4.4.9 *Lack of transition in the healthcare sector*

There is a need to transition between the legacy systems to the new systems which will be interconnected to IoT in healthcare. However, the critical transition is that of the healthcare workers like doctors, nurses, administration, etc. to embrace technology and IoT in healthcare.

“I once attended a very interesting conference where the guy had this one slide. He was showing two galaxies. We have a traditional healthcare industry being one galaxy, and another was the technology galaxy. These galaxies were colliding with

one another. The point is, especially with respect to new business models, the healthcare does not know how to deal with some of these things which are currently happening and emerging." Institution C

The healthcare sector could have the best and the latest IoT products and solutions in healthcare to automate some of the functions, but if the healthcare workers do not transition into using them, then the value of IoT in healthcare will never be realised, and this will have an impact on the diffusion of IoT in healthcare.

However, some of the respondents see this as an opportunity to reinvigorate and provide competitive advantage for the doctors.

The fact that we can give them mobility and the tools (IoT) makes their options a lot easier. If we give them the tools to do things better, they will certainly start to embrace technology. Secondly, the tools must be highly user friendly. There has to be a real value for the doctor to embrace this transition. The last is security. I am telling you now, if this system ever gets hacked once, the doctors will never trust you again. So, this is an opportunity for us technologists to bring forth best solutions." IoT SP E

4.4.10 *Lack of skills*

As an emerging technology, one of the critical diffusion conditions the study found was the IoT skills. These skills are at different levels. All the people deploying and maintaining these IoT networks need to be proficient in them. One of the respondents summarised the view of many as:

We have a lack of technical skills in general in South Africa. IoT is not so different that we can't skill people having different skills. This can be addressed. This is not insurmountable. We have an opportunity to skill people. IoT SP D

Some of the respondents believe that organisations offering and developing IoT are a good platform for IoT skills. However, the university has not yet embraced the IoT.

> *"The universities have a big way to go. You find in electronics, from third year forth year students do things which are related to IoT stuff but Big data is still a big problem. No one single university has a degree in data sciences."* IoT SP E

4.5 Main enabling conditions allowing for the diffusion of IoT in the healthcare sector of South Africa: research question 2

4.5.1 *Proliferation of smart phones*

Most of the respondents agree that, with the proliferation of the smart phones, the South African market has an opportunity to use this as a platform to diffuse IoT in healthcare.

> *"For most of the IoT solutions, smart phones are at the center. They are used for mobile applications which communicate with the IoT solution."* Vendor C

Smart phones have been seen as one of the critical IoT solution components where they can be used to integrate the IoT solution with a mobile app to give information to the user.

4.5.2 *Internet*

According to most of the respondents, South Africa has reached Internet maturity. Most of the areas in South Africa have Internet. This Internet comes in a form of physical connectivity (fibre, diginet, ADSL, etc.) or wireless connectivity (GSM, Wi-Fi, etc.). It is this Internet that enables the backhauling of the IoT data to the cloud provider where it needs to be collected, analysed and processed.

"We provide the backbone for Internet connectivity into the continent, we are in 17 countries now. We are building fibre for what you call sub-marine cables, to metro rails, we are big in that space. However, we are being pragmatic that this might take long to get someof this to the most remote part of the country, so we are trying to build a technology that also integrates with the existing GSM network." Vendor B

Another respondent from the private healthcare has also experienced this.

"All the hospitals are there, they now use the Internet to collaborate on a project, to form internet groups, people from different hospitals can form groups which were not possible before. We do have wireless, probably in most of our hospitals at this stage, all the big hospitals we have big wireless and we will actually utilise wireless on that perspective." Institution D

Some Internet service provider organisations go to an extent of providing the backbone interconnectivity for the IoT service providers to be able to build the IoT network.

"We have partnered with two IoT network providers for them to use our Internet backbone. They are providing connecting in the form of LoraWAN and SIGFOX." IoT SP D

However, one of the respondents believe that even if that Internet is readily available, there has not been any progress in connecting the government healthcare facilities.

"Even if we might have made progress in technology and network coverage, we have not made any progress in terms of connecting healthcare facilities in South Africa. And the things the healthcare facilities can be able to achieve is really high. The data bundles story makes me mad. We need to have proper broadband for sustainable internet connectivity. If we can to that level where internet becomes a secondary issue,

> *can you imagine the level of innovation we will get at these healthcare clinics."* Institution C

4.5.3 *Cloud services*

The respondents also confirmed that there is a high level of available cloud infrastructure in the South African market. It is this cloud infrastructure that enables the diffusion of IoT in healthcare.

> *"Few things happened which made IoT to be accelerated in South Africa. That is the cloud and bitcoin. The cloud allows us to take all these blocks of data into the cloud and centralise computing."* IoT SP E

Also, most of the respondents interviewed who have IoT solutions they are using or developing, they did not find any challenges with the cloud.

4.5.4 *Innovation*

The study has found that, against the lack of entrepreneurial drive in South Africa and the economic challenges, some organisations have been constantly innovating to bring forth IoT solutions in healthcare.

> *"We are not making investments in connectivity but what we are trying to do is make our products to be consumer packaged and ready. So, our products and solutions do not require massive investments in technology and data."* Institution E

Other respondents believe that the universities need to champion this initiative. The respondent summarised it as below:

> *"Universities are starting to look at IoT so as to incorporate it into their learning. We in South Africa have lost the passion and confidence to lead and innovate. We turn to rely on China and other countries to get things done. We need to move back in*

ensuring that South Africa does things by themselves. The universities need to champion this in earnest." IoT SP B

The study also found that, though some of the IoT solutions were not specific to IoT, there was numerous available IoT solutions in the market right now. Most of these solutions, should the regulations allow, can easily be adopted into the healthcare sector.

4.6 Improving conditions for the diffusion of IoT in healthcare sector of South Africa: research question 2

4.6.1 *Healthcare in a briefcase*

Some of the South African organisations have IoT healthcare solutions in the market already. One of the respondents described their solution:

> *We have got a device today that is sim card enabled, that works with a battery and is chargeable and can last for almost 6 months. You can drop it from the remotest part of South Africa, the remotest part of Limpopo, the remotest part of the villages has mobile phones. They don't even need 3G phones they just need 2G, we are able to give them the device to take home and be able to measure their blood pressure from home on their own. Once they've measured the blood pressure, the reading will be sent to their own phones and their next of kin who can be their accountability partner (their child, brother, etc.) or anyone in the world and they can instantly see that blood pressure reading. But the medical doctor is also integrated in that system, the system also sends a report to the medical doctor. The big data that comes through does the analytics and if there's anything wrong with the reading the medical doctor will either call the patient or the next of kin will the patient and ask them why the blood pressure is high? Are you taking your*

medication? So that's the first proposition we did, linked to chronic disease. Vendor B

Against the IoT constraints, the organisation has developed a solution to overcome the network availability constraints. They have developed a card which stores the customer details. With those details, the patient can go to any healthcare centre which has the solutions. Upon presenting their card, the healthcare practitioner can populate all healthcare records contained in the card.

> *"We basically bring in a brief case typical size of a brief case, we open it for you and we're able to do seven vital checks. Now why does this matter? If we put this at a clinic I suspect less than 1% of the entire Africans have ever done an electrocardiogram that could be an over estimation right, but to us that's a real problem. So, we want our viewers, every clinic in Africa whether rural or urban should have this device. We get to that clinic and we line up 100 villagers and we intend to do a full medical check-up for every one of them for a dollar, staff that could have taken them 500-800 dollars and we only doing it for 1 dollar. Part of what we want to do is to bring in disruptive technology, very disruptive technology that will really create that turn around that we need. So, we line them up and do the measurement and as soon as we're done with the measurement we give you your health card which has all your history in there. You can visit anyone anywhere they can be able to download your history is all cloud based, any medical doctor can access that."* Vendor B

The system also does telemedicine for the registered patients.

> *"We are able to deliver the patient health card that has got all the information which is very unique to the patient. That information stored on the card can also be used by public practitioners, government healthcare centres, health workers,*

health specialist and so forth. They now can be able to get good information on the effectiveness of the drugs against particular dieting, particular community, particular tribes and things like that. So, we've started on things like blood pressure and diabetes, we will be moving to things like cholesterol, some of the cancers where you actually have embedded sensors that can actually start to detect some of these things. But a lot of this diseases are lifestyle diseases, so a part of what we do today is once we connect you we also plug you in our health tips so where we now start to give health tips specific to an individual. Health tips, for instance in South African like pap or boerewors which might not be good for your hypertension so we come back to you and tell you what to avoid. The side effects of not being able to measure your blood pressure could be shared on the health tips platform, which can be accessed through your mobile phone." Vendor B

4.6.2 *Increasing number of IoT healthcare solutions users*

On a daily basis, more people are increasing in the use of IoT healthcare solutions in South Africa. This is due to the relentless work of some South African organisations that want to see to it that there is a balance between the sustainability of their organisation and customer's healthcare. Below quotes the respondent:

"We know that healthier people claim less. So, our take on this is that, you take the IoT technology which in our case refers to wearables and what you do is you create a very carefully set of rules, that allow members to be active and you aggregate the activity data and then you pay rewards based on how active they are" Institution E.

Another respondent also agrees.

> *“People have to see a benefit out of it. If people are not seeing a benefit, they are not going to adopt it. That benefit can only come in a better quality of life, it must reduce cost, there must be some tangible benefit to the consumer or it will be ignored.”*
> *IoT ISP A*

The organisation does this by rewarding their customers with rewards which means they pay less on their, for example, healthcare insurances, medical aid, car insurance, etc. In this case, the company saves costs and the customers also become healthier therefore benefiting both parties.

> *“By linking the wearable devices, we can monitor your heartrate and duration and give points to it. So, the simple metaphor is, if I go for a 30 minutes run, like I did on the 18th of July, I did a 30 minutes workout at 80% of my maximum heartrate and I got 300 points. And then this morning, I went for a 30 minutes run at 60% a heartrate and I got 100 points. So, we have created a currency of points and we know that by paying people like me points, which means they could get rewards then they pay less.”* Institution E

The organisation believes that when you drive the customers behaviour, you can diffuse the IoT in healthcare. For example, when you reward the customer with a digital watch under the conditions that they have to run some certain kilometres for a week or else they will have to pay for the watch, the customer start doing what is required because they know the consequences. In this way, there is a link in reducing claims by increasing customer healthcare over a long time.

Some of the organisations also have telemedicine solutions. They have a device which can be linked to the smart phone. You put a small drop of blood which can do many health vital signs. Because they have the customer integrated record (as part of their business), they are able to do analysis on the results and advise the customer accordingly. The system also is integrated with their platform where you can create and view doctors' appointments on your smart device.

> *"So, you have these things that can you put a little drop of blood on it and then it can give you your sugar rating, blood pressure monitors, east scales, treatment compliance,"* Institution E

One respondent agrees with this model by admitting that, the best way to move forward in IoT in healthcare sector is if people take their healthcare seriously and proactively become involved, instead of waiting for something to happen first.

> *"If I have to give you my own opinion, people need to take their health more seriously. In general, people only care about the health when they are sick. If you tell people you can get a free vaccination, few people would go. If you tell them it cost R250 and we are giving everyone R250 for all to go take the vaccine, all will come for the R250 – never mind them going to take the vaccination or not. I looked at one of the guys from the World Health Organisation who said health is produced at home, and it is only fixed at the clinic/hospital."* Institution C

4.6.3 *South African public clinics eHealth record system*

The government has developed a system which resolves some of the challenges with manual records and sharing of information in the public clinics. The summary of the solutions is described by the respondent as below:

> *"The implications of IoT in healthcare is phenomenon. We have built and deployed a healthcare record system to around 1500 clinics around the country and all of those patient data is on the central server. Therefore, it is fixing the sharing of data challenge. So, if the patient is moving from one clinic to the other, we can see exactly where they have been. If you have*

registered in one clinic, you don't have to register in another. This simple change has had a huge impact in the service the clinics provide. This system is only in the clinics. We have only started talking about expanding this system to the hospitals. This is because in the hospitals you usually have some system being used already unlike in the clinics." Institution C

4.7 Summary of findings

These findings show that healthcare regulation is the major enabler of the diffusion of IoT in the healthcare sector of South Africa. The regulations which would enable the diffusion of IoT in healthcare are still lacking and therefore constraining the diffusion of IoT in healthcare. Some of the other constraining factors include standardisation and interoperability, availability of IoT network, availability of cost effective IoT solutions, privacy and security vulnerabilities, high cost of data, socio-economic factors, low levels of entrepreneurial activities, lack of transition in the healthcare sector and lack of skills.

It was also found that there is an enabling environment for IoT to be diffused. This include the proliferation of smart phones, availability of the Internet, accessibility and availability of the cloud infrastructure, and innovation in the healthcare sector.

Although the are several conditions constraining the diffusion of IoT in healthcare, the enabling environment has allowed some organisations to develop, improve and bring forth to the market some of the IoT solutions in healthcare. These solutions included healthcare in a briefcase which did not require the IoT network, the increasing number of IoT healthcare users based on the innovations in the market, and the development of intelligent hospitals.

Whether the IoT in the healthcare sector of South Africa can be diffused depends on the conditions constraining this IoT diffusion. If these constraints can be overcome, and the factors favouring the development of IoT in healthcare effectively exploited, the IoT in healthcare will be diffused.

CHAPTER 5. DISCUSSION OF THE RESULTS

5.1 Introduction

This chapter discusses the findings of the study with reference to the literature on conditions allowing for the diffusion of IoT in the healthcare sector of South Africa. It considers the extent to which the findings are consistent with the literature, the extent to which they differ, and identifies instances where the findings may contribute to the expansion of the existing body of knowledge. The chapter begins with the discussion of the respondents, and proceeds to discuss each of the major findings in turn. It concludes with a summary of the discussion.

5.2 Overview of IoT in the healthcare sector of South Africa

The findings of the research are congruent with the literature, but of importance, the study further gave the details of the level of development thus far in both the public and private healthcare. It gave a context that there is huge difference in IoT progress between the public and private healthcare sectors.

The public healthcare sector was found to be battling with the basics and therefore losing the focus and prioritisation on IoT innovation. However, with the new strategies in place, this situation might change.

While the private sector was progressing in its diffusion of IoT in healthcare, it was mainly constrained by the regulations. This is consistent with the literature (Gray & Vawda, 2016; Herselman & Botha, 2016; Mars & Seebregts, 2008).

5.3 Main conditions constraining the diffusion of IoT in the healthcare sector of South Africa

5.3.1 *IoT diffusion against the highly regulated environment*

The notion that regulations constrain the diffusion of IoT in the healthcare sector was found in the literature (Ndubuaku & Okereafor, 2015; OECD, 2015a; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). It was discovered that most of the countries which managed to diffuse IoT in healthcare, was due to the enabled environment through the IoT in healthcare enabling regulations.

In the literature, one of the identified major conditions for the diffusion of IoT in healthcare is government creating policies to facilitate the transition toward digital and recognising the potential disruption. The regulatory environment and policies have played a major role in the success of IoT in countries such as Germany, USA, Mexico and Egypt. The literature had discovered that they have created an environment to enable the products and services of IoT to thrive (OECD, 2015a). They have done so by providing regulations and policies that would allow infrastructure development, entrepreneurship and consumption of these goods and services (Ndubuaku & Okereafor, 2015; OECD, 2015a; Sundmaeker, Guillemin, Friess, & Woelffle, 2010). This is in line with the finding of the study.

5.3.2 *Lack of IoT standardisation and therefore interoperability*

The study has discovered that lack of standardisation constrains interoperability, which therefore constrains the diffusion of IoT in the healthcare sector. This is consistent with the literature (Friess & Vermesan, 2015; Kulkarni & Sathe, 2014; Vermesan et al., 2016).

The results further realised the consistency in the four categories of standardisation, namely, platform, connectivity, business model and application.

5.3.3 *Availability of IoT network*

The study found that, thought the Internet has matured and is available in most of the areas, there is still a lack of IoT networks in South Africa. Apart from other reasons, this is mainly because IoT is an emerging technology and South Africa is still trying to adapt to it.

The literature only focused on the countries which have diffused IoT in healthcare. As a result, the study did not discuss the availability of the IoT network at length. This is because for IoT to be diffused, there has to be the network that supports the connectivity of those devices. As a result, it can be assumed that all countries which the literature mentioned as progressive in the diffusion of IoT in healthcare, have an IoT network.

Though there is lack of IoT networks in South Africa, the study has also discovered that there are several IoT development initiatives driven by both the public and private sector.

5.3.4 *Availability of cost effective IoT solutions*

The study found that, unsurprisingly, for the IoT to be diffused, there has to be accompanying IoT solutions. Moreover, these solutions need to be cost effective to allow mass adoption.

The literature has also found that there need to be a high uptake of products and services (OECD, 2015a). The study results are consistent with the literature.

In the South African context, the most important element of the results was the cost effectiveness of the solutions. The study found that most of the solutions were not developed in South Africa. As such, these solutions tend to become more expensive because they are imported.

5.3.5 *Privacy and security vulnerabilities*

The study found that privacy and security go hand in hand. This are very important in the healthcare environment. The literature also found that stringing of digital security and privacy is one of the major conditions allowing for IoT to be diffused in the healthcare.

Though the study results and literature are consistent, the study found that South Africa, with its high regulations, makes privacy and security have high requirements.

5.3.6 *High cost of data*

The study found that, apart from all other conditions, the cost of data in South Africa is high. As a result, this cost needs to come down so as to accommodate the mass adoption of IoT solutions, which would lead to the diffusion of IoT in healthcare.

The high cost of data was found to be due to different factors, including the lack of IoT network development. In the literature, Ndubuaku and Okereafor (2015) also listed the factors below as the conditions which could make the IoT diffused in Africa: cheaper cost of sensors, cheaper cost of bandwidth, cheaper processing, introduction of Big Data analytics, widespread use of smart phones, ubiquitous wireless network, alternative energy and ultralow power technologies. This is consistent with the study results.

5.3.7 *Socio-economic factors*

The study has found that South Africa has socio-economic challenges which are constraining it to have IoT diffused in healthcare sector. This socio-economic challenge included the economic environment, lack of employment, high prevalence of poverty and inequality.

These socio-economic factors are specific to the South African environment and these are not in line with the literature.

5.3.8 *Low levels of IoT entrepreneurial activities (localisation)*

Entrepreneurship is important for localisation and economic development. The study found that low levels of IoT entrepreneurial activities constrain the diffusion of IoT in healthcare. This is consistent with the literature. The literature found that for IoT to be diffused, there needs to be a fostering of entrepreneurship and employment (Jamalipour et al., 2016; Manyika et al., 2015; OECD, 2015a; Sundmaeker, Guillemin, Friess, & Woelffle, 2010; Vermesan & Friess, 2014).

In the USA, the country has been seeing a growth in the investment of the venture capitalist (OECD, 2015a). The study has found that in South Africa, there is low investment in new ventures. This constrains new venture creation. The study did not focus on the reason for low levels of IoT entrepreneurial activities. However, the study found that the government needed to play an active role in enabling the environment for entrepreneurship to thrive.

5.3.9 *Lack of transition in the healthcare sector*

In the healthcare sector, the healthcare practitioners are part of the integral change into IoT. If the practitioners successfully transition into using technology and automation, the study has found that this would enable IoT to be diffused.

This transition also includes the transition of the system from legacy into modernised technology solutions. The literature also found that, to date, there has not been any standardisation to seamlessly integrate the legacy healthcare systems and the IoT-based systems (Friess & Vermesan, 2015; Ndubuaku & Okereafor, 2015).

The literature did not find specifics on the transition of the healthcare practitioners.

5.3.10 *Lack of skills*

The study found lack of skills to be one of the conditions that need to be eradicated to enable diffusion of IoT in the healthcare. This is consistent to the literature. The literature found that countries that have taken an advantage of the transition to IoT have embraced skills development as one of the key factors to enable the country to be successful in its digital strategy (Behmann, 2015; Macgillivray et al., 2016; Presidenza del Consiglio dei Ministri, 2015; The German Federal Government, 2014).

5.4 Main enabling conditions allowing for the diffusion of IoT in the healthcare sector of South Africa

5.4.1 *Proliferation of smart phones*

The study found that South Africa has a high penetration of smart phones. It was also discovered that the smart phones are used to interconnect to IoT ecosystem whereby playing an integral part in the success of IoT.

The literature has also found the same condition to be true. The literature believes that the smart phones are being used for, apart from other things, disease management, records tracking, research and clinical referencing (Behmann & Wu, 2015; Friess & Vermesan, 2015; Jamalipour et al., 2016)

5.4.2 *Internet*

South Africa has a high prevalence of Internet. This is good for the diffusion of IoT as Internet is the basis for IoT (Behmann & Wu, 2015; Friess & Vermesan, 2015; Minerva et al., 2015; Xu et al., 2014).

This is consistent with the literature. The literature has found that access to the Internet will enable IoT to be successful in unlocking the potential economic value, allow consumers to be able to consume the IoT products and service which in turn, will make IoT successful (Behmann & Wu, 2015; Friess & Vermesan, 2015; Minerva et al., 2015; Xu et al., 2014).

5.4.3 *Cloud infrastructure*

Literature has shown that cloud computing is one of the key enablers for IoT to function (Carnaz & Nogueira, 2016; Jamalipour et al., 2016; Sathi & Gayathri, 2016). It offers IoT-based healthcare the facility for ubiquitous access to shared resources over the network.

The study has found that South Africa has well-developed cloud services. This is consistent with the literature.

5.5 Improving conditions for the diffusion of IoT in healthcare sector of South Africa

The study has found that, though under tough challenges like regulations and lack of available IoT network, some companies have managed to be innovative and have brought forth solutions for IoT in the healthcare. These solutions which are currently available in the South African market, include healthcare in a briefcase, amongst others.

Other positive contributions to the improving conditions included the increasing number of IoT healthcare solutions. However, the major challenge against these solutions being diffused is the lack of standardisation and interoperability.

The literature has discovered that around the globe, there are many IoT solutions addressing the healthcare sector. The study is consistent with the global IoT environment.

South Africa has also developed an eHealth strategy which is addressing the need to digitalise the healthcare sector. It is through this strategy that the appropriate regulations will be formed to support the strategy. Consistent with the literature, the literature found that more countries which are leading in digitalisation and IoT have also developed strategies which are aimed at the common goal of leveraging IoT to unlock the economic potential it offers (OECD, 2015a).

5.6 Conclusion

The findings of this study accord in many respects with the international literature on conditions allowing for the diffusion of IoT in healthcare. However, there are findings that are specific to South Africa, most notably the effect that the country's significant socio-economic divide, and the relatively low levels of entrepreneurial activity, each have on the prospects for diffusion of IoT in healthcare.

More than merely being a description of the state of IoT in the healthcare sector of South Africa, these findings, when viewed together with the literature, provide some guidance on what could be done to further develop the sector.

CHAPTER 6. CONCLUSIONS & RECOMMENDATIONS

6.1 Introduction

This study has examined the conditions that would allow IoT to be diffused in the healthcare sector of South Africa. It has established the main conditions for the diffusion of IoT in the healthcare sector of South Africa. The study has further established the main conditions that could allow the discovered IoT conditions to be appraised in the healthcare sector of South Africa. In doing so, this research has answered the research questions and fulfilled its aim as outlined in the Introduction chapter.

This chapter summarises the main findings of the study and presents conclusions on the research problems identified in Chapter 1. On the basis of these conclusions, it makes recommendations for different stakeholders promoting the diffusion of IoT in the healthcare sector of South Africa. It concludes with suggestions for further research arising from this study.

6.2 Conclusion of the study

The Internet of Things has seen remarkable developmental growth globally. This development and growth of IoT has led to the diffusion of IoT in healthcare for different countries. This diffusion of IoT in healthcare has enabled countries to automate some of the functions in healthcare, thereby providing quality of life to the citizens.

However, this diffusion of IoT in healthcare has not been seen in South Africa. The study has found a number of major conditions constraining the diffusion of IoT in the healthcare sector of South Africa. These includes:

- The highly regulated healthcare sector which lead to some of the IoT solutions not being offered in the South African market. However, South Africa has developed the strategy called eHealth which requires development of new regulations to support this initiative. It is expected that in the near future, there will be regulations which would allow IoT to be diffused in the healthcare sector of South Africa.

- Lack of IoT standardisation which leads to lack of interoperability. The lack of standardisation makes platforms, connectivity, business models and applications not interoperable. Lack of interoperability leads to isolated platforms, connectivity, business models and application being isolated and highly customised. This is a global problem. Different initiatives have been developed to provide standardisation. This is a work in progress.
- Lack of available IoT network. IoT devices have specific requirements which are different from the normal Internet devices. Amongst others is the requirements for a long battery life of the devices. South Africa has seen several initiatives to build the LoRaWAN, a network specific to IoT. However, with the lack of spectrum amongst other challenges, these developments have been slow. Against these factors, South African organisations are using the current spectrum to dedicate to IoT in the meantime.
- Lack of available cost effective IoT solutions. One of the major factors contributing to this lack was that most of the IoT devices and solutions are not developed locally and are therefore imported. The other major factor is related to the regulatory environment, which makes developing the solutions a futile excise.
- Privacy and security of the patients and users is of paramount importance. Because of lack of standardisation, it is challenging to have consistent security with associated privacy.
- The cost of data is too high for IoT in South Africa. This will constrain the diffusion of IoT as the devices will be producing a lot of data and therefore a more cost-effective solution is required. Some of the reasons for the high cost of data in South Africa is lack of spectrum to develop the specific IoT network to cater for the IoT devices.
- South African socio-economic factors such as poverty, inequality and unemployment plays a major role in the diffusion of IoT in healthcare. This is because for IoT to be diffused in healthcare, there must be a high

adoption of the products and services. If the community is poor and unemployed, this goal might not be realised.

- Low level of IoT entrepreneurial activities which lead to lack of localisation. This lead to products and solutions being expensive which contribute directly to the constraints for the diffusion of IoT. Moreover, the lack of these entrepreneurial activities makes South African IoT healthcare to have limited products and solutions.
- Lack of transition in the healthcare. This transition is in the form of medical practitioners appreciating the change IoT brings in healthcare and also, the legacy system being able to be integrated into the IoT systems.
- Lack of skills. Apart from other reasons, this is because IoT is an emerging technology. With other constraining factors like low levels of entrepreneurial activities, it constrains the skills development further.

There are, however, a number of factors that favour the diffusion of IoT in the healthcare sector of South Africa. These include:

- Proliferation of smart phones. It was found that smart phone penetration is high. These smart phones form part of some of the IoT solutions and therefore, create a favourable condition for the diffusion of IoT.
- Available and accessible Internet. South Africa has a matured Internet environment where many areas have available Internet access. Internet is one of the fundamental necessities of IoT.
- Accessible cloud services. South Africa has many competing organisations offering both private and public could. Cloud computing forms part of the services required for IoT to be diffused.
- Innovativeness of the South African communities. Against the highly regulated industry and all associated constraints such as standardisation, South Africans have found a way to be innovative and offer products and services in healthcare using IoT.

From these findings, it is possible to conclude that the conditions allowing for the diffusion of IoT in healthcare in South Africa are favourable.

South Africa has the capacity and capability to develop all the conditions that have enabled other countries to diffuse IoT in healthcare. At the centre of this is the provision of the supportive regulatory environment to enable the development, uptake and diffusion of IoT in healthcare sector of South Africa.

6.3 Recommendations

The findings of this study suggest a number of actions that could be taken by different stakeholders to improve the conditions allowing for IoT to be diffused in the healthcare sector of South Africa. In most instances, these actions will require cooperation and collaboration.

The government needs to provide the regulations and policies which will enable diffusion of IoT in the healthcare. These regulations and policies need to be created with the level of security and privacy which is associated with the healthcare in mind. As such, the government needs to balance the diffusion of IoT in healthcare and the personal privacy and security of the users.

The successful implementation of IoT will benefit the government by moving the healthcare from the public healthcare facilities to the homes. This will free the government to innovate and diffuse IoT in their practices. As such, even though today the government is embroiled in the day-to-day basic operations, they need to continuously innovate the public healthcare facilities to enable them to be IoT ready.

The government needs to take a leading role in ensuring the creation of a platform (such as incubations) for IoT entrepreneurship to allow entrepreneurship in IoT to thrive. This should be created with appropriate incentives which will ensure entrepreneurs and investors get involved in IoT in their numbers. This would create products and solutions which are developed locally, thereby reducing the import costs and enabling the diffusion of IoT in the healthcare sector.

The private healthcare providers have been hard at work ensuring automation takes place in their environment. However, they have been constrained by the regulations which at times do not allow them to diffuse IoT. They should therefore form a partnership with the government to ensure the proper policies are discussed and laid out.

The healthcare insurance plays a vital role in the diffusion of IoT in healthcare. We have also witnessed that people adopt IoT in healthcare by their numbers when they are incentivised for their actions. As such, healthcare-related insurance providers should innovate their offering to include IoT solutions with appropriate associated incentives for their customers to use IoT healthcare solutions.

As of today, almost all IoT vendors producing sensors, networking equipment, actuators, electronics and software are not South African organisations. This has led to high prices for this necessary IoT equipment. The recommendation to the vendors is therefore that they should leverage on the economies of scale to bring down the prices. This would allow mass implementation of the IoT solutions and uptake.

South Africa has also seen a low level of entrepreneurship activities in IoT. There is high incentive for the entrepreneurs in the South African market as there are only a few organisations taking part in this industry, especially in healthcare. Entrepreneurs and investors are recommended to invest their resources in this industry.

We have different types of IoT service providers in South Africa. The major ones are service carriers that build the IoT networks to enable those developing the IoT solutions to use their network to connect the devices. The second ones are those that take different products from vendors to provide a comprehensive solution to the market, leveraging on the IoT network. The carrier service providers are recommended to continue to develop the IoT network to allow for the required network for the IoT devices to interconnect. Both these services providers should contribute to the IoT skills development which is necessary for the diffusion of IoT in healthcare.

South Africa has a desperate of skills in the IoT industry. It is recommended that the education institutions be involved in offering programs which are specific to the IoT to develop the skill base for the country.

6.4 Suggestion for further research

Given the relative lack of research on IoT in South Africa, this study is necessarily exploratory in nature. The findings point to a number of areas where further research could, and should, be undertaken. Such research would be able to explore further issues raised in the course of this study and probe issues that fall outside the scope of this study.

Among the areas that require further research is the establishment of the actual impact of IoT in healthcare in South Africa. This would include the extent of the changes it would produce, the required changes that need to be made for this impact to be realised, and the required landscape for this to be realised.

There is also a need for research that could assist in the development of public policy to promote IoT in healthcare. Such research could include a comparative survey of international best practice on IoT in healthcare. It would also be useful to survey the views of private healthcare providers, healthcare insurances, IoT vendors, entrepreneurs, investors, IoT service providers and other role-players on the development of those policies specific for the South African environment.

Further research could assist in the development of IoT standardisation for the healthcare sector. Such research could include the current standardisation landscape, compare it with the other information technology standards that have been successfully created and give a recommendation on how the standardisation of IoT in healthcare can be accelerated.

Finally, there is a need to examine how South Africa’s relatively low levels of entrepreneurial activity could be improved. This could include research into the view of the investors and entrepreneurs regarding the South African business environment for IoT in healthcare.

REFERENCES

Alex, G., Varghese, B., Jose, J. G., & Abraham, A. (2016). A Modern Health Care System Using IoT and Android. *International Journal on Computer Science and Engineering (IJCSE)*, *8*(4), 117–121.

Andersson, M. (2015). Short range low power wireless devices and Internet of Things (IoT). *U-Blox*, *R01*, 1–15.

Andreini, F., Crisciani, F., Cicconetti, C., & Mambrini, R. (2010). Context-aware location in the internet of things. In *2010 IEEE Globecom Workshops, GC'10* (pp. 300–304).

Andrews, C. (2015). *The Internet of Things : An Overview*. Washington, USA: GovLoop.

Ashton, K. (2009). That "Internet of Things" Thing. *RFiD Journal*, 4986. Retrieved from http://www.itrco.jp/libraries/RFIDjournal-That Internet of Things Thing.pdf%5Cnpapers3://publication/uuid/8191C095-0D90-4A17-86B0-550F2F2A6745

Asia, A. H., & Exclusive, P. (2015). Intelligent Healthcare Facilities – What does it take to get there ? *A HIMSS Asia Pacific exclusive article*, (December), 1–4.

Asongu, S. A. (2015). The Impact of Mobile Phone Penetration on African Inequality. *International Journal of Social Economics*, *42*(8), 706–716.

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, *54*(15), 2787–2805.

Barcena, M. B., & Wueest, C. (2015). Insecurity in the Internet of Things.

Barusch, A., Gringeri, C., & George, M. (2011). Rigor in Qualitative Social Work Research: A Review of Strategies Used in Published Articles. *Social Work Research*, *35*, 11–19.

Begum, S. F. U., & Begum, I. (2017). Smart Health Care Solutions Using IOT. *International Journal & Magazine of Engineering, Technology, Management and Research*, *4*(3), 10–15.

Behmann, F., & Wu, K. (2015). *Collaborative Internet of Things (C-IoT): for Future Smart Connected Life and Business*. Brighton: John Wiley & Sons Ltd.

Berg, R., Oiso, H., Sung, S., Paltridge, S., & Diaz-Pines, A. (2014). Working Party on Communication Infrastructures and Services Policy. *Organisation for Economic Co-Operation and Development*, (2014), 75.

Bien, B., & Selvanathan, H. (2014). Capitalizing on The Internet of Things : A Primer, (February), 2–5. Retrieved from http://www.techradar.com/news/mobile-computing/capitalizing-on-opportunities-presented-by-the-internet-of-things-1262670

Biernacki, P., & Waldorf, D. (1981). Snowball Sampling: Problems and Techniques of Chain Referral Sampling. *Sociological Methods & Research*, *10*(2), 141–163.

Bluhm, D. J., Harman, W., Lee, T. W., & Mitchell, T. R. (2011). Qualitative research in management: A decade of progress. *Journal of Management Studies*, *48*(8), 1866–1891.

Bowen, G. a. (2005). Preparing a qualitative research-based dissertation:

Lessons learned. *The Qualitative Report*, *10*(2), 208–222.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(May 2015), 77–101.

Brody, P., & Pureswaran, V. (2014). Device democracy. *IBM Global Business Services Executive Report*. Retrieved from http://m2mworldnews.com/download/white-papers/IBM-Saving-the-future-of-IoT.pdf

Bryman, A. (2004). Quantity and Quality in Social Research. *Social Research Today*. Retrieved from http://books.google.nl/books?id=7pyt0yqQAcQC

Byung-Keun, K. (2005). *Internationalizing the Internet: the Co-evolution of Influence and Technology*. Boston, Massachusetts, USA: Edward Elgar Publishing.

Carnaz, G. J. F., & Nogueira, V. (2016). *An Overview of IoT and Healthcare*. (S. Abreu & V. B. Nogueira, Eds.). Évora: Escola de Ciências e Tecnologia da Universidade de Évora. Retrieved from http://hdl.handle.net/10174/19998

Certini, G., Leonard, S., Brawn, J. D., Robinson, S. K., Iii, F. R. T., Wilkie, M. L., … Norman, M. S. (2014). Purposive sampling. *Oikos*.

Chen, S., Xu, H., Liu, D., Hu, B., & Wang, H. (2014). A vision of IoT: Applications, challenges, and opportunities with China Perspective. *IEEE Internet of Things Journal*, *1*(4), 349–359.

Christians, C. G. (2005). Ethics And Politics In Qualitative Research. In N. K. L. Y. S. Denzin (Ed.), *Handbook of Qualitative Research* (pp. 139–164). SAGE Publications, Inc. Retrieved from http://www.sagepub.com/sites/default/files/upmbinaries/5317_Denzin_and_Lincoln_Chapter_6.pdf

Coetzee, L., & Eksteen, J. (2011). The Internet of Things – Promise for the Future? An Introduction. *Conference Proceedings*, 978–1.

Collector, D., & Module, F. G. (2011). Qualitative Research Methods Overview. *Qualitative Research Methods A Data Collectors Field Guide*, *2005*(January), 1–12.

Creswell, J. W. (2003). Research design Qualitative quantitative and mixed methods approaches. *Research Design Qualitative Quantitative and Mixed Methods Approaches*, 3–26.

Creswell, J. W., & Miller, D. L. (2000). Determining Validity in Qualitative Inquiry. *Theory Into Practice*, *39*(3), 124–130.

Curry, L. A., Nembhard, I. M., & Bradley, E. H. (2009). Qualitative and mixed methods provide unique contributions to outcomes research. *Circulation*.

Denzin, N. K., & Lincoln, Y. S. (2000). The discipline and practice of qualitative research. *Handbook of Qualitative Research*.

Department of Health South Africa. (2012). *National eHealth Strategy, South Africa 2012/13-2016/17*. Pretoria: Department of Health.

Department of Health South Africa. (2015). *National Health Insurance for South Africa: Towards Universal Health Coverage*. *White Paper* (Vol. 40). Retrieved from http://www.doh.gov.za/list.php?type=National Health Insurance

Econex. (2013). The South African Private Healthcare Sector : Role and Contribution to the Economy. *South African Private Pracitioners Forum*, *32*(December), 1–65. Retrieved from http://www.mm3admin.co.za/documents/docmanager/f447b607-3c8f-4eb7-8da4-11bca747079f/00060290.pdf

Fan, P., & Zhou, G. (2011). Analysis of the business model innovation of the technology of internet of things in postal logistics. *2011 IEEE 18th International Conference on Industrial Engineering and Engineering Management*, *Part 1*, 532–536.

Feki, M. A., Kawsar, F., Boussard, M., & Trappeniers, L. (2013). The Internet of Things: The Next Technological Revolution. *IEEE Computer Society*, *35*(5), 24–25.

Fischer, S. (2014). Ongoing Hospital Innovation in the Developed World. *IEEE PULSE*, 14–15.

Fleisch, E., Weinberger, M., & Wortmann, F. (2014). Business Models for the Internet of Things. *Bosch IoT Lab*, 1–18.

Folk, C., Hurley, D. C., & Payne, J. F. X. (2015). the Security Implications, (February).

Friess, P., & Vermesan, O. (2015). *Building the Hyperconnected Society*. Aalborg, Denmark: River Publishers.

Gapchup, A., Wani, A., Gapchup, D., & Jadhav, S. (2016). Health Care Systems Using Internet of Things. *International Journal of Innovative Research in Computer and Communication Engineering*, *4*(12), 20896–20903.

Garcia-Macias, J. A., Alvarez-Lozano, J., Estrada, P., & Aviles Lopez, E. (2011). Browsing the internet of things with sentient visors. *Computer*, *44*(5), 46–52.

Gilley, B. (2014). Moving Beyond Regulatory Mechanisms : A Typology of Internet Control Regimes by Richard Reid Hunt A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Political Science Thesis Committee : David Kinsella Wu-c.

Gillwald, A., Moyo, M., & Stork, C. (2012). What is happening in ICT in South Africa: A supply-and demand-side analysis of the ICT sector. *Evidence for ICT Policy Action*, (7). Retrieved from http://www.researchictafrica.net/docs/Policy Paper 7 - Understanding what is happening in ICT in South Africa.pdf

Govindarajan, V., & Ramamurti, R. (2013). Delivering World- Class Health Care, Affordably. *Harvard Business Review*, (November).

Gray, A., & Vawda, Y. (2016). *South African Health Review*. (A. Padarath, J. King, E. Mackie, & J. Casciola, Eds.), *South African Health Review 2016* (May 2016). Durban, South Africa: Health Systems Trust.

GSMA. (2015). The Mobile Economy Report: Europe 2015, 1–46. Retrieved from http://www.gsmamobileeconomy.com/

GSM Association. (2014). *Understanding the Internet of Things (IoT)*. *GSM Association*. Connected Living Series, New Fetter Lane, London UK.

Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication & Technology*, *29*(2), 75–91.

Guba, E. G., & Lincoln, Y. S. (1982). Epistemological and methodological bases of naturalistic inquiry. *Educational Communication & Technology*, *30*(4), 233–252.

Guba, E. G., & Lincoln, Y. S. (1994). Competing Paradigms in Qualitative Research. *Handbook of Qualitative Research*, 105–117.

Herdon, M., Botos, S., Várallyai, L., Bayo-Moriones, A., Lera-López, F., Bozionelos, N., … Zrt, N. I. (2015). Decreasing the Digital Divide by Increasing E-Innovation and E-Readiness Abilities in Agriculture and Rural Areas. *International Journal of Agricultural and Environmental Information Systems*, *6*(1), 1–18.

Herselman, M., & Botha, A. (2016). *Strategies , Approaches and Experiences : Towards building a South African Digital Health Innovation Ecosystem*. Pretoria, South Africa: CSIR Meraka.

Hiremath, S., Yang, G., & Mankodiya, K. (2014). Wearable Internet of Things: Concept, architectural components and promises for person-centered healthcare. *Proceedings of the 2014 4th International Conference on Wireless Mobile Communication and Healthcare - "Transforming Healthcare Through Innovations in Mobile and Wireless Technologies", MOBIHEALTH 2014*, 304–307.

Hwang, Y., Kim, M. G., & Rho, J.-J. (2016). Understanding Internet of Things (IoT) diffusion : Focusing on value configuration of RFID and sensors in business cases (2008 – 2012). *Information Development*, *32*(4), 969–985.

International Telecommunication Union. (2012). Overview of the Internet of things. *Series Y: Global Information Infrastructure, Internet Protocol Aspects and next-Generation Networks - Frameworks and Functional Architecture Models*, 22.

Internet World Stats. (2016). World Internet Users Statistics and 2016 World Population Stats. *Internet usage statistics The Internet Big Picture*. Miniwatts Marketing Group. Retrieved from http://www.internetworldstats.com/stats.htm

Islam, S. M. R., Kwak, D., Kabir, H., Hossain, M., & Kwak, K.-S. (2015). The Internet of Things for Health Care : A Comprehensive Survey. *Access, IEEE*, *3*, 678–708.

Jack, C. L., & Mars, M. (2013). Informed consent for telemedicine in South Africa: A survey of consent practices among healthcare professionals in Durban, KwaZulu-Natal. *South African Journal of Bioethics and Law*, *6*(2), 55–59.

Jamalipour, A., Nikookar, H., & Ruggieri, M. (2016). *Digitising the Industry Internet of Things Connecting the Physical, Digital and Virtual Worlds*. (O. Vermesan & P. Friess, Eds.), *Journal of Chemical Information and Modeling* (Vol. 49). Gistrup, Denmark: River Publishers.

Kerravala, Z. (2014). It's time for business to embrace the Internet of Things, (November).

Kulkarni, A., & Sathe, S. (2014). Healthcare applications of the Internet of Things: A Review. *2014 Third IEEE International Colloquium in Information Science and Technology (CIST)*, *5*(5), 6229–6232.

Kumari, P., López-benítez, M., Myoung, G., Kim, T.-S., & Minhas, A. S. (2016). Wearable Internet of Things - from Human Activity Tracking to Clinical Integration. *IEEE*.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. *Naturalistic Inquiry*.

Lopez Research. (2013). An Introduction to the Internet of Things (IoT). *Lopez Research Llc*, *Part 1. of*(November), 1–6.

LoRa Alliance. (2015). *A technical overview of LoRa and LoRaWAN*. San Ramon, Califonia, USA. Retrieved from https://www.lora-alliance.org/portals/0/documents/whitepapers/LoRaWAN101.pdf

Lund, D., Morales, M., Turner, V., & MacGillivray, C. (2014). *Worldwide and Regional Internet of Things (IoT) 2014 – 2020 Forecast : A Virtuous Circle of Proven Value and Demand*. Framingham, USA: IDC.

Macgillivray, C., Siviero, A., Clarke, R. Y., Xiang, K. K. M., Cansfield, M., Feblowitz, V. T. J., & Lamy, L. (2016). *IDC FutureScape : Worldwide Internet of Things 2016 Predictions*. Framingham, USA: IDC.

Madakam, S., Ramaswamy, R., & Tripathi, S. (2015). Internet of Things (IoT): A Literature Review. *Journal of Computer and Communications*, *3*(3), 164–173.

Manyika, J., Chui, M., Bisson, P., Woetzel, J., Dobbs, R., Bughin, J., & Aharon, D. (2015). The Internet of Things: Mapping the value beyond the hype. *McKinsey Global Institute*, (June), 144.

Mars, M., & Seebregts, C. (2008). Country Case Study for e-Health: South Africa. *eHealth Research and Innovation Platform*, 1–46. Retrieved from http://ehealth-connection.org/files/resources/County Case Study for eHealth South Africa.pdf

Minerva, R., Biru, A., & Rotondi, D. (2015). Towards a definition of the Internet of Things (IoT). *IEEE Internet Things*, 1–86. Retrieved from http://iot.ieee.org/images/files/pdf/IEEE_IoT_Towards_Definition_Internet_of_Things_Revision1_27MAY15.pdf

Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad Hoc Networks*, *10*(7), 1497–1516.

Miraz, M. H., Ali, M., Excell, P. S., & Picking, R. (2015). A review on Internet of Things (IoT), Internet of Everything (IoE) and Internet of Nano Things (IoNT). *2015 Internet Technologies and Applications, ITA 2015 - Proceedings of the 6th International Conference*, 219–224.

Morton-Williams, J. (1985). Making qualitative research work—aspects of administration. *Applied Qualitative Research*, 27–44.

Mukhopadhyay, S. C. (2014). *Internet of Things: Challenges and Opportunities*. Palmerton, New Zealand: Springer International Publishing.

Ndubuaku, M., & Okereafor, D. (2015). Internet of Things for Africa: Challenges and Opportunities, *9*(November 2015), 23–31.

Niewolny, D. (2013). How the Internet of Things Is Revolutionizing Healthcare. *White Paper*, *October*, 1–8. Retrieved from http://cache.freescale.com/files/corporate/doc/white_paper/IOTREVHEALCARWP.pdf

Niranjana, S., & Balamurugan, A. (2015). Intelligent E-Health Gateway Based Ubiquitous Healthcare Systems in Internet of Things. *International Journal of Scientific Engineering and Applied Science*, *1*(9), 284–290.

OECD. (2015a). *OECD Digital Economy Outlook 2015*. https://doi.org/http://dx.doi.org/10.1787/9789264232440-en

OECD. (2015b). *OECD economic surveys: South Africa*. Paris, France: OECD Publishing. https://doi.org/10.1787/eco_surveys-zaf-2013-en

Okereafor, D. (2015). State of Internet of Things Deployment in Africa and Its Future : the, (15), 4–7.

Olsen, C. (2008). The Mobile Economy. *Adweek*, (35), 11–11.

Onwuegbuzie, A. J., & Leech, N. L. (2007). Sampling Designs in Qualitative Research : Making the Sampling Process More Public. *The Qualitative Report*, *12*(2), 19–20.

Patton, M. Q. (1987). Strategic Themes in Qualitative Inquiry. *How to Use Qualitative Methods in Evaluation*.

Petäjäjärvi, J., Mikhaylov, K., Hämäläinen, M., & Iinatti, J. (2016). Evaluation of LoRa LPWAN technology for remote health and wellbeing monitoring Evaluation of LoRa LPWAN Technology for Remote Health and Wellbeing Monitoring. *Medical Information and Communication Technology (ISMICT), 2016 10th International Symposium On. IEEE*, (March), 1–5.

Pope, C., & Mays, N. (1995). Qualitative research: rigour and qualitative research. *Br Med J*, *311*, 109–12.

Presidenza del Consiglio dei Ministri. (2015). *Strategia italiana per la banda ultralarga*. Retrieved from http://www.infratelitalia.it/wp-content/uploads/2015/03/bul_4_marzodef_0.pdf

Purfield, C. M., Im, F., & Inchauste, G. (2014). South Africa economic update: Fiscal Policy and Redistribution in an Unequal Society. *Worldbank*, (November 2014), 51. Retrieved from http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2014/10/30/000470435_20141030130616/Rendered/PDF/921670WP0P131400SAEU60for0web01029b.pdf

Regeringen. (2014). *Vækstplan for Digitalisering af Danmark*. København: Henvendelse om udgivelsen kan i øvrigt ske til. https://doi.org/978-87-93214-46-0

Revathi, R., Vijani, S., & Vijanu, S. (2015). Intelligent health care services based on Iot. *International Journal of Scientific & Engineering Research*, *6*(4), 500–503. Retrieved from http://www.ijser.org/researchpaper%5CINTELLIGENT-HEALTH-CARE-SERVICES-BASED-ON-IoT.pdf

Rifkin, J. (2014a). Digital Europe : The Rise of the Internet of Things and the Integration of the Single Market, 1–9.

Rifkin, J. (2014b). *The zero marginal cost society: the internet of things, the collaborative commons, and the eclipse of capitalism*. London: Macmillan.

Rubin, H. J., & Rubin, I. S. (2005). *Qualitative Interviewing: The Art of Hearing Data*. *Qualitative Interviewing: The Art of Hearing Data*. Thousand Oaks, CA.: Sage Publications.

Sathi, H., & Gayathri, P. (2016). Case study on Health care Using Internet of Things. *International Journal of Current Trends in Engineering & Research*, *2*(5), 368–374.

Schenkel, G., & Stev. (2012). Taking Leadership in a Digital Economy, (November).

Schulte, S. R. (2013). *Cached: Decoding the Internet in global popular culture*. *Cached: Decoding the Internet in Global Popular Culture*. New York: NYU Press.

Scully, P. (2016). 5 Things To Know About The IoT Platform Ecosystem. Retrieved from http://iot-analytics.com/5-things-know-about-iot-platform/

Senatore, L. (2010). A Critical Analysis of Factors Influencing Internet Diffusion in South Africa and its Implications on the Rollout of e-Government

Services. *World*.

Sreekanth, K., & Nitha, K. (2016). A Study on Health Care in Internet of Things. *International Journal on Recent and Innovation Trends in Computing and Communication*, *4*(2), 44–47.

Stankovic, J. A. (2014). Research Directions for the Internet of Things. *Internet of Things Journal, IEEE*, *1*(1), 3–9.

Sundmaeker, H., Guillemin, P., Friess, P., & Friess, P. (2010). *Vision and Challenges for Realising the Internet of Things*. Brussels, Belgium: Publications Office of the European Union.

Sundmaeker, H., Guillemin, P., Friess, P., & Woelffle, S. (2010). *Vision and Challenges for Realising the Internet of Things* (Vol. 1). Brussels, Belgium: European Union.

Takpor, T. O., & Atayero, A. A. (2015). Integrating Internet of Things and EHealth Solutions for Students' Healthcare. *World Congress on Engineering, Wce 2015, I*(*I)*, 265–268.

Tapscott, D. (1996). The Digital Economy: Promise and Peril in the Age of Networked Intelligence. *Academy of Management Perspectives*, *10*(2), 69–71.

Tapscott, D. (2014). *The Digital Economy: Rethinking Promise and Peril in the Age of Networked Intelligence*. New York, USA: McGraw-Hill.

The Federal Government. (2014). *Digital Agenda 2014 – 2017*. München: Federal Ministry for Economic Affairs and Energy. Retrieved from https://www.digitale-agenda.de/Content/DE/_Anlagen/2014/08/2014-08-20-digitale-agenda-engl.pdf?__blob=publicationFile&v=6

Tobergte, D. R., & Curtis, S. (2013). Distributed and Cloud Computing. *Journal of Chemical Information and Modeling* (Vol. 53).

Vermesan, O., & Friess, P. (2014). *Internet of Things Applications - From Research and Innovation to Market Deployment*. Aalborg, Denmark: River Publisher. Retrieved from https://books.google.com.br/books?id=kw2doAEACAAJ

Vermesan, O., Friess, P., Guillemin, P., Serrano, M., Bouraoui, M., Freire, L. P., … Malo, P. (2016). Research , Innovation and Deployment. *European Research Cluster on the Internet of Things*, 15–114.

Vujovic, V., Perisic, B., & Maksimovic, M. (2015). A Custom Internet of Things Healthcare System. *CISTI*, (JUNE), 653–658.

Wang, X. H., Yu, T. M., & Zhang, J. H. (2014). Study on earnings forecast of internet of things in China - Based on Anylogic simulation model. *International Conference on Management Science and Engineering - Annual Conference Proceedings*, 96–102.

Weber, R. P. (1990). *Basic content analysis*. Thousand Oaks, CA.:Sage.

Wengraf, T. (2003). Qualitative Research Interviewing: Biographic Narrative and Semi-Structured Methods. *Human Resource Development Quarterly*, *14*(1), 117–122.

Whitmore, A., Agarwal, A., & Da Xu, L. (2015). The Internet of Things-A survey of topics and trends. *Information Systems Frontiers*, *17*(2), 261–274.

Xu, L. Da, He, W., & Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics*, *10*(4), 2233–2243.

Yinbiao, S., Lee, K., Lanctot, P., Juanbin, F., Hao, H., Chow, B., … Qui, W. (2014). Internet of Things: Wireless Sensor Networks. *Internation Electronic Commision*, (December), 1–78.

APPENDIX A: Africa 2016 Internet penetration

Africa 2016 population and the Internet users statistics for 2016 (Internet World Stats, 2016)

AFRICA	Population (2016 Est.)	Internet Users 31-Dec-2000	Internet Users 30-Jun-2016	Penetration (% Population)	Internet % Africa
Algeria	40 263 711	50 000	11 000 000	27,3%	3,3%
Angola	20 172 332	30 000	5 951 453	29,5%	1,8%
Benin	10 741 458	15 000	1 232 940	11,5%	0,4%
Botswana	2 209 208	15 000	620 000	28,1%	0,2%
Burkina Faso	19 512 533	10 000	1 894 498	9,7%	0,6%
Burundi	11 099 298	3 000	526 372	4,7%	0,2%
Cabo Verde	553 432	8 000	224 183	40,5%	0,1%
Cameroon	24 360 803	20 000	4 311 178	17,7%	1,3%
Central African Rep.	5 507 257	1 500	224 432	4,1%	0,1%
Chad	11 852 462	1 000	387 063	3,3%	0,1%
Comoros	794 678	1 500	59 242	7,5%	0,0%
Congo	4 852 412	500	357 471	7,4%	0,1%
Congo, Dem. Rep.	81 331 050	500	3 101 210	3,8%	0,9%
Cote d'Ivoire	23 740 424	40 000	5 230 000	22,0%	1,6%
Djibouti	846 687	1 400	105 163	12,4%	0,0%
Egypt	90 067 793	450 000	33 300 000	37,0%	10,1%
Equatorial Guinea	759 451	500	181 657	23,9%	0,1%
Eritrea	6 674 489	5 000	67 000	1,0%	0,0%
Ethiopia	102 374 044	10 000	4 288 023	4,2%	1,3%
Gabon	1 738 541	15 000	670 197	38,5%	0,2%
Gambia	2 009 648	4 000	373 865	18,6%	0,1%
Ghana	26 908 262	30 000	7 958 675	29,6%	2,4%
Guinea	11 780 162	8 000	770 000	6,5%	0,2%
Guinea-Bissau	1 726 170	1 500	70 000	4,1%	0,0%
Kenya	45 925 301	200 000	31 985 048	69,6%	9,7%
Lesotho	1 947 701	4 000	250 000	12,8%	0,1%
Liberia	4 195 666	500	348 240	8,3%	0,1%
Libya	6 411 776	10 000	2 400 000	37,4%	0,7%
Madagascar	23 812 681	30 000	1 100 000	4,6%	0,3%
Malawi	17 715 075	15 000	1 080 620	6,1%	0,3%
Mali	16 955 536	18 800	1 186 888	7,0%	0,4%
AFRICA	Population (2016 Est.)	Internet Users 31-	Internet Users 30-	Penetration (%	Internet % Africa

		Dec-2000	Jun-2016	Population)	
Mauritania	3 596 702	5 000	455 553	12,7%	0,1%
Mauritius	1 339 827	87 000	803 896	60,0%	0,2%
Mayotte (FR)	220 300	n/a	107 940	49,0%	0,0%
Morocco	33 322 699	100 000	20 207 154	60,6%	6,1%
Mozambique	25 303 113	30 000	1 503 005	5,9%	0,5%
Namibia	2 212 307	30 000	470 000	21,2%	0,1%
Niger	18 045 729	5 000	351 892	2,0%	0,1%
Nigeria	181 562 056	200 000	92 699 924	51,1%	28,0%
Reunion (FR)	867 687	130 000	380 000	43,8%	0,1%
Rwanda	12 661 733	5 000	3 216 080	25,4%	1,0%
Saint Helena (UK)	4 513	n/a	1 800	39,9%	0,0%
Sao Tome & Principe	194 006	6 500	48 806	25,2%	0,0%
Senegal	13 975 834	40 000	7 260 000	51,9%	2,2%
Seychelles	92 430	6 000	50 220	54,3%	0,0%
Sierra Leone	5 879 098	5 000	260 000	4,4%	0,1%
Somalia	10 616 380	200	500 000	4,7%	0,2%
South Africa	54 777 809	2 400 000	26 841 126	49,0%	8,1%
South Sudan	12 042 910	n/a	1 914 823	15,9%	0,6%
Sudan	36 108 853	30 000	9 307 189	25,8%	2,8%
Swaziland	1 435 613	10 000	389 051	27,1%	0,1%
Tanzania	51 045 882	115 000	7 590 794	14,9%	2,3%
Togo	7 552 318	100 000	430 482	5,7%	0,1%
Tunisia	11 037 225	100 000	5 408 240	49,0%	1,6%
Uganda	37 101 745	40 000	11 924 927	32,1%	3,6%
Western Sahara	554 795	n/a	27 000	4,9%	0,0%
Zambia	15 066 266	20 000	2 711 928	18,0%	0,8%
Zimbabwe	14 229 541	50 000	6 759 032	47,5%	2,0%
TOTAL AFRICA	**1 158 355 663**	**4 514 400**	**330 965 359**	**28,6%**	**100,0%**

APPENDIX B: Lists of institutions interviewed

Interview Code	Interviewee	Organisation Description	Legal form	Relationship to IoT
Institution A	Research group leader	Scientific research and development organisation	State-owned company	IoT research organization
IoT SP A	National manager	Builds and operates fibre optic networks to interconnect different municipalities, towns and cities	Private company	Enable the interconnectivity
Institution B	CEO	The digital marketing firm	Private company	Market IoT solutions
Vendor A	Solution Architect	Multinational enterprise manufacturing servers, storage and networking devices	Public company	Development of IoT solutions, and manufacture of IoT and related communications devices.
Vendor B	CEO	Pan-African IoT company that research and manufacture IoT healthcare products and solutions	Private company	Development of IoT solutions, and manufacture of IoT and related communications devices.
Vendor C	Territory Manager	Multinational enterprise manufacturing servers, storage and networking devices	Public company	Development of IoT solutions, and manufacture of IoT and related communications devices.
IoT SP B	Group Business Development Executive	A firm that delivers smart technologies across multiple disciplines such as telecommunications, information technology, energy and industry	Public company	
IoT SP C	Executive	Service provider of wireless connectivity and enterprise enhancement solutions.	Subsidiary of a public company	The firm has built a LPWAN network for IoT devices. They have also developed the platform for IoT development.
IoT SP D	Chief Technology Officer	An Internet Protocol communications service provider provides connectivity services, cloud offerings as well as carrier services to corporate enterprises	Subsidiary of a private company	

Vendor D	Product and category manager	The firm develops, manufactures, and sells networking hardware, telecommunications equipment, and other high-technology services and products.	Public company	IoT is one of the firm's specialities.
IoT SP E	Managing Director and the business partner	Information technology professional services firm.	Subsidiary of a private company	IoT services provider
IoT SP F	Strategy Executive	A digital solutions firm providing information and communications technology services	Subsidiary of a public company	IoT services provider
Vendor E	Manager	Multinational enterprise manufacturing servers, storage and networking devices	Public company	Development of IoT solutions, and manufacture of IoT and related communications devices.
IoT SP G	Managing Executive	an African mobile communications company, providing voice, messaging, data and converged services	Public company	The firm has built a LPWAN network for IoT devices. They have also developed the platform for IoT development.
Institution C	Head of research unit	South African scientific research and development organisation	State-owned company	Responsible for developing eHealth solutions and regulations for the government. The Solutions touches a lot on IoT and its operation.
Institution D	Executive	Private healthcare provider owning more than 30 hospitals.	Public company	The firm has IoT enabled facilities
IoT SP H	Executive	an African mobile communications company, providing voice, messaging, data and converged services	Public company	The firm has built a LPWAN network for IoT devices. They have also developed the platform for IoT development.
Institution E	Chief Information Officer	A healthcare insurance firm	Public company	Develops and integrates healthcare IoT healthcare solutions to their platforms.
Institution F	Executive	Independent regulatory body of the South African government	State-owned company	Regulate the spectrum

APPENDIX C: Interview guides

Sample interview questions for one role players (IoT SP, Vendors):

1. What is your position within your organisation and what do you do in that capacity? **[Context]**

2. Does your organisation have any ongoing or/and upcoming projects related to Internet of Things possibly in the health care sector? **[IoT investment]**

3. Is your organisation having any current or future projects to enable greater access to the internet for the majority of South Africans such that it would enable high adoption of IoT? **[access to internet]**

4. Does your organisation have any IoT solution it is developing, selling or using? FOLLOW UP: What is your organization strategy for IoT development, uptake and market? **[Development and uptake of IoT products and services, available IoT solutions in the market]**

5. In what way are the government and other public organisations providing the enabling environment for your organisation to develop and diffuse your IoT solutions? FOLLOW UP: What else could be done to enable the environment for IoT to thrive? **[Government policies; Strengthening of IoT security and patients' privacy; protection of competition; IoT standardisation; IoT devices and software multivendor interoperability; available skills, skills development, education and training; ICT research, development and innovation]**

6. What are the opportunities and challenges, if any, does your organisation see in the South African health care sector for the successful implementation of Internet of Things? **[Opportunities and challenges]**

7. In your own opinion, what could be done to improve conditions for enabling Internet of Things to thrive in South African health care sector? **[Research Questions #2]**

Sample interview questions for non-core players (institutions):

1. What is your position within your organisation and what do you do in that capacity? **[Context]**
2. Does your organisation have any ongoing or/and upcoming projects related to Internet of Things possibly in the health care sector? **[IoT investment]**
3. Is your organisation having any current or future projects to enable greater access to the internet for the majority of South Africans such that it would enable high adoption of IoT? **[access to internet]**
4. Does your organisation have any IoT solution it is developing, selling or using? FOLLOW UP: What is your organization strategy for IoT development, uptake and market? **[Development and uptake of IoT products and services, available IoT solutions in the market]**
5. In what way is the South African environment providing the enabling environment for your organisation to develop and diffuse your IoT solutions? FOLLOW UP: What else could be done to enable the environment for IoT to thrive? **[Government policies; Strengthening of IoT security and patients' privacy; protection of competition; IoT standardisation; IoT devices and software multivendor interoperability; available skills, skills development, education and training; ICT research, development and innovation]**
6. What are the opportunities and challenges, if any, does your organisation see in the South African health care sector for the successful implementation of Internet of Things? **[Opportunities and challenges]**
7. In your own opinion, what could be done to improve conditions for enabling Internet of Things to thrive in South African health care sector? **[Research Questions #2]**

APPENDIX D: Illustration of thematic map