An Internet of Things Model for Field Service Automation

By

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Submitted in fulfilment of the requirements for the degree of Master Commercii in Computer Science and Information Systems at the Nelson Mandela Metropolitan University

April 2017

Acknowledgements

I would like to dedicate this dissertation to my father, George Bwalya Kapeso. The completion of my master's dissertation was inspired by the sacrifices you made and continuous encouragement you offered. I would like to thank God for the strength to overcome the challenges that I encountered during this research. I would also like to express my sincere heartfelt gratitude to my supervisor Dr Brenda Scholtz for the academic support and for always being there for me as a mentor when I needed encouragement or when I wanted to give up. I am also grateful to my family and friends for their patience, encouragement, and support throughout this research.

I would like to thank the SYSPRO for providing the necessary research funding to complete this research. Finally, I appreciate the NMMU RCD, for their financial assistance towards this research.

Summary

Due to the competitive nature of the global economy, organisations are continuously seeking ways of cutting costs and increasing efficiency to gain a competitive advantage. Field service organisations that offer after sales support seek to gain a competitive advantage through downtime minimisation. Downtime is the time between service requests made by a customer or triggered by equipment failure and the completion of the service to rectify the problem by the field service team. Researchers have identified downtime as one of the key performance indicators for field service organisations. The lack of real-time access to information and inaccuracy of information are factors which contribute to the poor management of downtime. Various technology advancements have been adopted to address some of the challenges faced by field service organisations through automation. The emergence of an Internet of Things (IoT), has brought new enhancement possibilities to various industries, for instance, the manufacturing industry.

The main research question that this study aims to address is "*How can an Internet of Things be used to optimise field service automation?*" The main research objective was to develop and evaluate a model for the optimisation of field services using an IoT's features and technologies. The model aims at addressing challenges associated with the inaccuracy or/and lack of real-time access to information during downtime. The model developed is the theoretical artefact of the research methodology used in this study which is the Design Science Research Methodology (DSRM). The DSRM activities were adopted to fulfil the research objectives of this research.

A literature review in the field services domain was conducted to establish the problems faced by field service organisations. Several interviews were held to verify the problems of FSM identified in literature and some potential solutions. During the design and development activity of the DSRM methodology, an IoT model for FSA was designed. The model consists of:

- The Four Layered Architecture;
- The Three Phase Data Flow Process; and
- Definition and descriptions of IoT-based elements and functions.

The model was then used to drive the design, development, and evaluation of "proof of concept" prototype, the KapCha prototype. KapCha enables the optimisation of FSA using IoT techniques and features. The implementation of a sub-component of the KapCha system, in fulfilment of the research. The implementation of KapCha was applied to the context of a smart lighting environment in the case study. A two-phase evaluation was conducted to review both the theoretical model and the KapCha prototype.

The model and KapCha prototype were evaluated using the Technical and Risk efficacy evaluation strategy from the Framework for Evaluation of Design Science (FEDS). The Technical Risk and Efficacy strategy made use of formative, artificial-summative and summative-naturalistic methods of evaluation. An artificial-summative evaluation was used to evaluate the design of the model. Iterative formative evaluations were conducted during the development of the KapCha. KapCha was then placed in a real-environment conditions and a summative-naturalistic evaluation was conducted. The summative-naturalistic evaluation was used to determine the performance of KapCha under real-world conditions to evaluate the extent it addresses FSA problems identified such as real-time communication and automated fault detection.

Keywords: *Field Services, Field Service Management, Field Service Automation, Internet of Things, KapCha, Design Science Research, Framework for Evaluation of Design Science.*

Declaration

I, Mando Mulabita Kapeso, hereby declare the dissertation, ***An Internet of Things Model for Field Service Automation***, for Magister Commercii in Computer Science and Information Systems is my own independent work. All sources used or quoted have been indicated and acknowledged by means of complete references. This dissertation has not been previously submitted for assessment to any other university or completion of any other qualification.

Mando Mulabita Kapeso

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List of Acronyms

AI	Artificial Intelligence
API	Application Program Interface
CI	Computational intelligence
CPS	Cyber-Physical Systems
DSR	Design Science Research
DSRM	Design Science Research Methodology
EAM	Enterprise Asset Management
ERP	Enterprise Resource Planning
FEDS	Framework for Evaluation of Design Science
FSA	Field Service Automation
FSM	Field Service Management
HEI	Higher Education Institution
IoT	Internet of Things
KPIs	Key Performance Indicators
M2M	Machine to Machine
NMMU	Nelson Mandela Metropolitan University
OEM	Original Equipment Manufacture
REST	Representational State Transfer
RO	Research Objective
RQ	Research Question
SOA	Service Oriented Architecture
WFM	Workforce Management

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Chapter 1. Introduction

1.1. Background

In a competitive global economy where every organisation is looking at ways to cut costs, increase efficiency and gain a competitive advantage, Field Service Management (FSM) becomes critical as it plays a vital role in customer satisfaction and loyalty (Alazraki, 2015). Field Service Management refers to the support provided by hardware and software in the management of field service operations. FSM also involves the management of the activities and processes that are associated with field services. FSM operations include tracking vehicles, scheduling and dispatching employees, and integrating of these operations with a back-office system for inventory, logistics and marketing. FSM includes elements such as Enterprise Asset Management (EAM), maintenance support, sensor networks, Radio Frequency Identification (RFID) tags, telematics, technical support, contract management and product life-cycle management. FSM is a generic market within the comprehensive service management domain.

The FSM market has seen a steady growth and evolution in the last 10 years (McNeill, Maoz, & Wong, 2014). This growth and evolution can be attributed to new technology developments, as technology is a driver in better after-sales service innovations (Agnihothri, Sivasubramaniam, & Simmons, 2002; Hinckley, Pierce, Sinclair, & Horvitz, 2000; McNeill, Maoz, & Wong, 2013). Field service management is a subset of the broader service market. Agnihothri et al. (2002) identify two types of services namely facility-based services and field-based services. The former refers to the customer gaining access to a service by going to the facilities of a service provider. Examples of facilities that offer this kind of service are insurance and banking institutions. However, even though in recent years remote provision of these services has eliminated the need for customers to physically go to the facility, most customers still see the need to go to banking institutions to gain access to some services (Pikkarainen, Pikkarainen, Karjaluoto, & Pahnila, 2004). With field-based services, customers receive an on-site or remote service. Field-based services can further be categorised into three categories, as follows:

- Pickup/delivery for example services such as package and mail services;
- Emergency services for instance fire, police and ambulance services; and
- After-sales services, for example, equipment installation, maintenance and repair.

This research will focus on after sales field services and will hereafter refer to them as field services. Field services typically involve the installation of equipment, on-site training, performing scheduled and emergency maintenance on-site, and on/off-site repairs. Such services could be part of the initial purchase, as a warranty service, or as a part of a service contract. Behara and Lemmink (1997) provide a description of a typical field service process. The customer usually initiates field repair or emergency maintenance service calls. Despatchers at a central facility receive the calls for the service organisation. The call is initially evaluated and on-line service is provided when possible. In other cases, the service call is assigned to a technician or is placed in a queue. The technician calls the customer assigned, schedules a visit if required, and proceeds to the location to diagnose and repair the equipment. The availability of any spare parts that may be needed, determines when the equipment will become available to the customer. The call is cleared after the repair is completed. The customer billing and feed-back processes could then be initiated by the service company. Figure 1-1 illustrates the field service process described. As can be noted the service technician is placed at the centre of the process to indicate his/her significant role as a critical internal customer. The level of customer service provided will depend on how effectively the technicians are supported by their despatcher, local managers, and the company's spare parts unit.

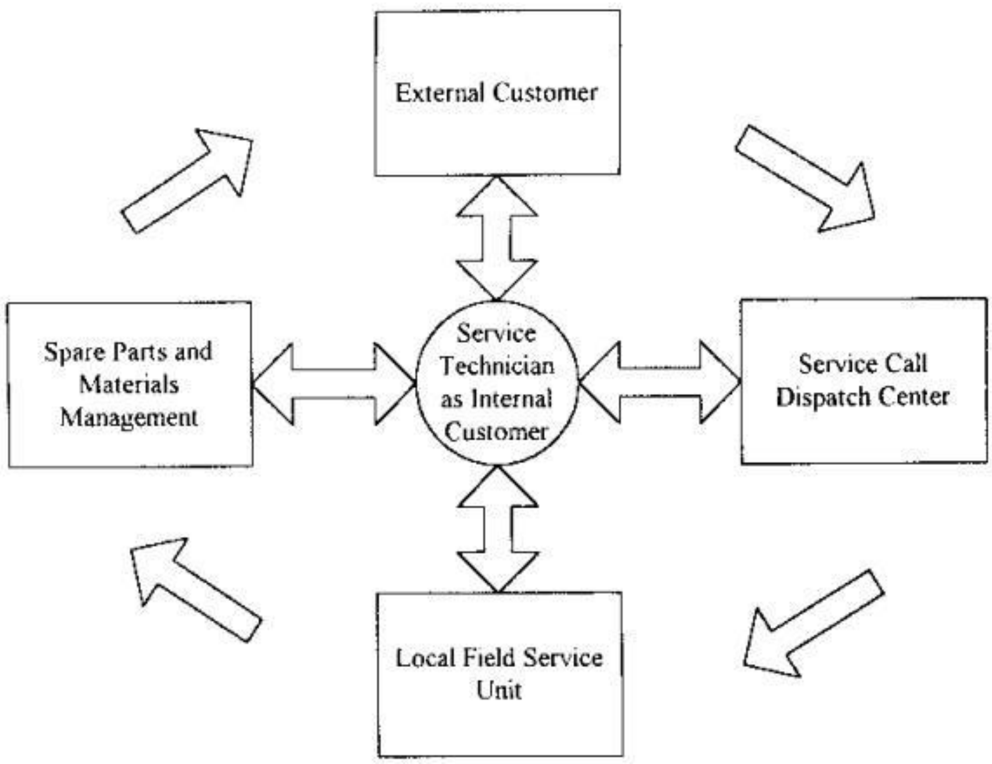

Figure 1-1 Field Service Process (Behara & Lemmink, 1997)

The use of technology to optimise FSM has been referred to as Field Service Automation (FSA) by researchers (Agnihothri et al., 2002; Rotter, 2016). The trend towards automation has been driven by advances in technology. Through various technology advances, human society is moving towards an era of always being connected. The era of human connectivity, has resulted in society having a corresponding need to connect with objects, referred to as smart objects, which impact their daily lives. A new concept has arisen as a result of these smart objects and is known as "Internet of Things" (IoT). IoT describes a context where objects are connected to the Internet, or become part of it, and are accessible through a network providing their location and current operational status (Coetzee & Eksteen, 2011). Bi, Xu and Wang (2014) define IoT as an extension of the Internet which provides real time information about objects in the physical world and leads to innovative services with high efficiency and productivity. Kortuem, Kawsar, Fitton and Sundramoorthy (2010) describe IoT as a decentralised system of smart objects with sensing, processing, and network capabilities.

1.2. Problem Statement

Several researchers (Agnihothri et al., 2002; Behara & Lemmink, 1997; Lehtonen, Ala-Risku, & Holmström, 2012; Petrakis, Hass, & Bichler, 2012) have identified operational challenges faced by organisations with regards to FSM in the field service industry, such as inaccuracy, a lack of real-time access to information by employees in the field, and the management of downtime. Inaccurate or missing information, whether relating to the customer or to the equipment under maintenance or repair (Lehtonen et al., 2012), results in the failure of field service visits by field employees. Information such as customers' service history, service contract agreements and location are not always readily available to field service employees in the field (Agnihothri et al., 2002; Lehtonen, 2005). Downtime is the time between a customer's request for service and the completion of the service by the field service team to rectify the problem (Agnihothri et al., 2002; Lehtonen et al., 2012). Inaccurate information or the lack of real-time access to the necessary information are factors which contribute to the poor management of downtime (Lehtonen et al., 2012). Other factors that affect FSM are the poor scheduling of field employees and the management of field service resources such as service parts (Petrakis et al., 2012).

Researchers have established various performance measures for field services. Downtime is the most profound performance measure recognised by researchers (Agnihothri et al., 2002; Behara & Lemmink, 1997; Lehtonen et al., 2012; Petrakis et al., 2012). Agnihothri et al., (2002) phased downtime into two subcategories, response time and on-site time. Response time is the time between the customer's request and the service team's arrival on-site. On-site time is the duration of time taken between the service team's arrival at the customer's site and the rectification of the problem.

Researchers have encouraged the use of technology to improve field services (Agnihothri et al., 2002; Chang & Yen, 2012; Z. Xu,Ming,Zheng,et al., 2014) and various technological advancements have been adopted in order to address some of the challenges faced by field service organisations (Petrakis et al., 2012). The emergence of an IoT has brought new enhancement possibilities to various industries, for instance, the manufacturing industry (Bi et al., 2014; Coetzee & Eksteen, 2011). The use of an IoT to address these challenges needs to be researched.

The problem statement for this research is therefore as follows:

Field service organisations face a problem of operational optimisation due to the inaccuracy of and the lack of real-time access to information.

1.3. Aim of Research

Field Service Automation that utilises the techniques of an IoT can help field service organisations address the challenges identified: inaccurate information, a lack of real-time access to information, and downtime management. The aim of this research is:

To design a model with techniques and technologies that utilise an IoT to support the optimisation of FSA projects.

1.4. Relevance and Envisaged Contribution

The integrity of information and the management of downtime are common challenges faced by field service organisations (Agnihothri et al., 2002; Behara & Lemmink, 1997; Lehtonen et al., 2012; Petrakis et al., 2012). Apart from the research that has been conducted to identify the challenges faced by field based service organisations, researchers have identified the need to find solutions to efficiently address these challenges (Agnihothri et al., 2002; Behara & Lemmink, 1997; Petrakis et al., 2012). Lehtonen et al., (2012) identified the role of information accuracy in the efficient delivery of field services, and emphasised the need for research to be conducted to establish a concept of information integrity management which is supported by information availability. Furthermore, it is necessary to determine how field employees' preparedness impacts on an organisation's ability to meet customer needs and how this, in turn, affects the organisation's operational needs (Agnihothri et al., 2002).

Information inaccuracy and the lack of real-time access to information can be addressed with the automation of field services using technological innovations (Agnihothri et al., 2002). An IoT is a new-era technological paradigm said to optimise how businesses in various industry sectors operate (Bi et al., 2014; McNeill et al., 2013). The IoT offers possibilities such as the ability of objects to communicate job status and location with minimal human interaction, which can help address the challenges faced by field service organisations.

Limited research has been found regarding the application of techniques for an IoT within the field service industry, although extensive research has been conducted in the application of an IoT within the manufacturing and supply chain sectors (Bi et al., 2014; Borgia, 2014). Bi et al. (2014) evaluated the application of an IoT in modern manufacturing and its impact on the manufacturing process. Further research conducted by Borgia (2014) and Fleisch (2010) investigated various applications of an IoT with the supply chain and manufacturing processes amongst the various areas identified.

Therefore, the contribution of this research will be the design, development and evaluation of an IoT model for the optimisation of field services. The contribution of this research is to identify techniques utilising an IoT that can be used to optimise FSA and improve the success of these projects. Criteria will be established that can be used to evaluate the success of the identified techniques. One of these criteria is downtime. The techniques selected after evaluation will be used as possible implementations to optimise FSA. Furthermore, the research will also establish the relevant technologies needed in order to implement an IoT.

1.5. Research Questions

The following is the main research question to be addressed by this research:

- *How can an IoT be used to optimise FSA?*

The main research question will be answered by addressing the following sub research questions:

RQ 1. What problems are faced by field service organisations providing after sales services as identified by literature and within a real-world context?

RQ 2. What technologies can be used to optimise FSA and enable the growth of the IoT?

RQ 3. What are the challenges of an IoT?

RQ 4. What are the requirements and objectives of an IoT-based FSA system?

RQ 5. How should a model to support optimisation of FSA be designed?

RQ 6. How can a FSA system be developed using the model?

RQ 7. How can the KapCha prototype optimise FSA within the smart lighting environment in the case study?

The purpose of the research conducted in this dissertation was address the research questions presented. The research questions were addressed by means of the research objectives.

1.6. Research Objectives

The main research objective of this research is:

To develop a model for the optimisation of FSA using IoT techniques and technologies.

The following sub-objectives have been identified to achieve the main research objective:

RO 1. Identify problems faced by after sales field service organisations.

RO 2. Identify the technologies that can be used to optimise FSA and enable the growth of the IoT.

RO 3. Identify the problems faced by an IoT.

RO 4. Determine the real-world problems faced by field service organisations.

RO 5. Identify the requirements and objectives of an IoT-based FSA system.

RO 6. Design an IoT model to optimise FSA.

RO 7. Develop an FSA system (the KapCha prototype) using the model.

RO 8. Determine, by means of evaluation, whether the KapCha prototype can optimise FSA within the smart lighting environment in the case study.

1.7. Scope and Constraints

The focus of the research at hand is on optimising FSA using IoT techniques. IoT techniques will be investigated and selected to optimise the activities of FSA. The activities of field services to be considered in this research pertain to the location of vehicles and field service employees, the scheduling of employees and real-time access to information between field employees and the back-office system. A prototype will then be developed using the selected techniques.

The research at hand will not include such components of FSM as billing and invoice processing. These processes fall outside the scope of the research as they are built into the ERP system to be used. Furthermore, consideration of the use of embedded devices as “things” within an IoT will be limited, as the embedding of sensors and actuators is a topic more appropriate to electrical and mechanical engineering.

1.8. Research Methodology and Dissertation Structure

A research methodology is a set of principles, practices and procedures that is applied to an existing problem in a particular field of research (Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007). It allows researchers to produce and present research that is accepted as valuable and rigorous. The selected research methodology for this research is the Design Science Research (DSR) methodology, which shall be discussed further in Section 2.3.

The research strategies used in the context of the DSR methodology within this research include:

- A literature Study;
- Interviews;
- A case study, and
- The Framework for Evaluation in DSR (FEDS).

The research topic and the purpose of this research have been introduced in Chapter 1. The problem statement, research questions and objectives of the research have been discussed, and the constraints of the research and the methodology to be used have been identified.

Chapter 2 will review the research methodology and strategies to be used in this research. The chapter will illustrate how the DSR methodology will be used to address the research questions (Section 1.5) and research objectives (Section 1.6) identified. Chapter 3 will identify the problems faced by after-sales field service organisations as well as the KPIs of FSM using a literature review. Chapter 3 will also discuss an IoT and its elements. The technology enablers and challenges of an IoT will be established as well as its application in various industry sectors. The technologies, architectures and features associated with implementation of IoT will also be identified.

Chapter 4 will report on the interview findings of FSA in a real-world context. The chapter will also discuss the design of an IoT Model for FSA using a set of selected technologies and architectures of IoT. The techniques to be used for the design and implementation will be identified and evaluated based on the selection criteria established during the literature study and interviews conducted.

An evaluation plan of the artefact developed in Chapter 4 will be discussed in Chapter 5. The evaluation plan will discuss the evaluation strategy and methods to be used during the evaluation process. The development of the KapCha prototype and its formative evaluation shall also be presented in Chapter 5.

Chapter 6 will report on the findings of the evaluations. Interview findings on the model design shall be reported on in Chapter 6. Results from the experiments conducted to evaluate components of the KapCha prototype shall also be reported on in Chapter 6.

Chapter 7 will be the concluding chapter of the research. The findings from Chapter 6 will be interpreted and discussed in Chapter 7. Conclusions will then be made on whether the artefact optimises FSA. The observations and limitations of the research will also be discussed in detail. The contributions of this research and possible future research will be determined. An outline of the dissertation is illustrated in Figure 1-2.

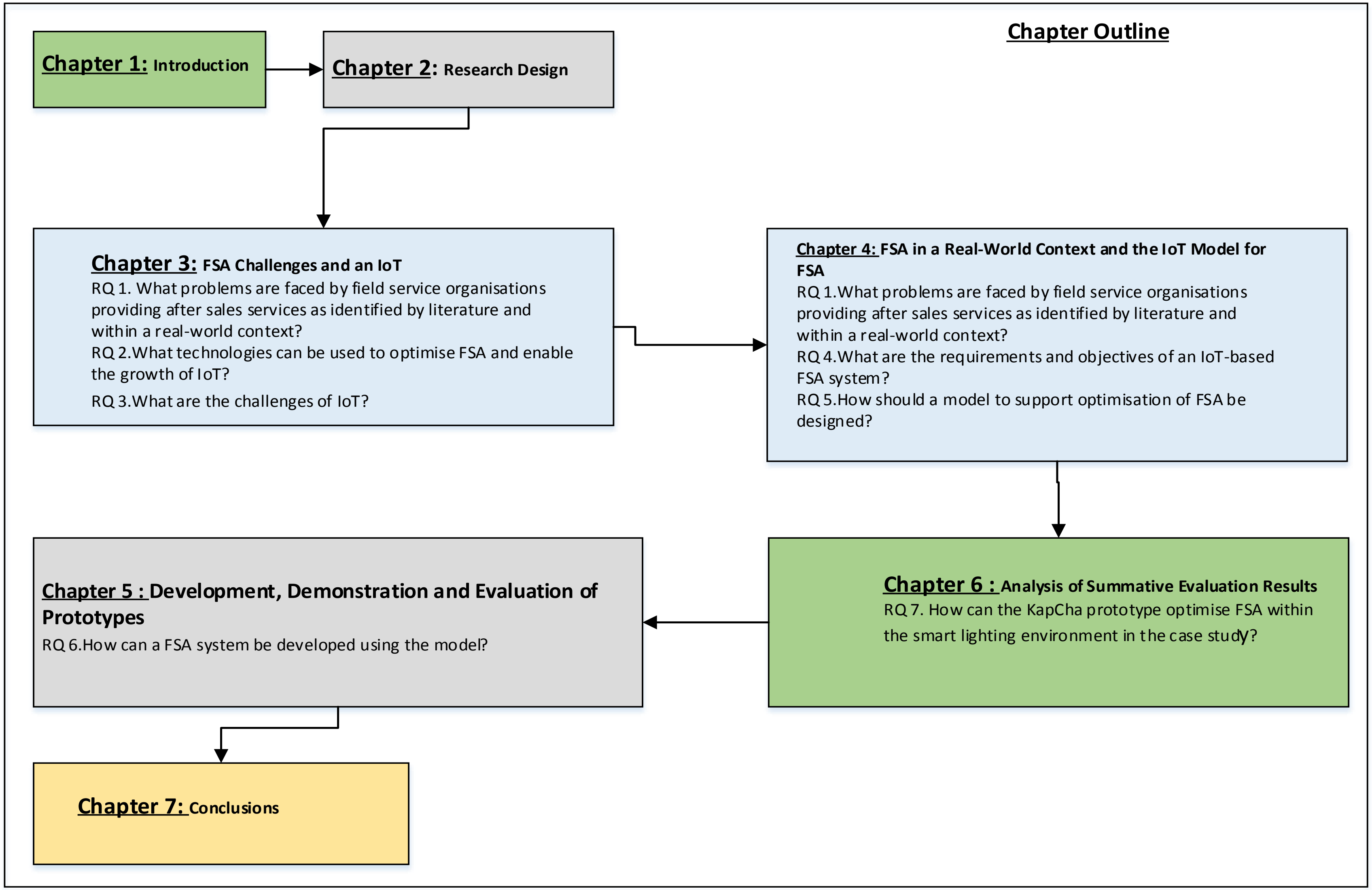

Figure 1-2 Dissertation Chapter Outline

Chapter 2. Research Design

2.1. Introduction

The preceding chapter provided an overview of the research to be presented in this dissertation. The research questions and objectives were identified, as well as the scope and the constraints of the research. The aim of this chapter is to discuss the research methodology and design to be undertaken in this study.

In Section 2.2 the "research onion" developed by Saunders, Lewis and Thornhill (2007) will be introduced to illustrate the phases covered when developing a research strategy. The research methodology to be used in this dissertation is the Design Science Research (DSR) methodology (Section 2.3). The DSR methodology will be applied in conjunction with other research methods and approaches (Section 2.4). The ethical considerations to be undertaken with the sample group shall be presented in Section 2.5. The chapter concludes with a summary of the research design.

2.2. The Research Onion: Research Concepts and Methods

The research onion developed by Saunders et al. (2007) provides an activity guideline through which a research methodology can be designed. The research onion was developed in order to describe the stages the researcher will have to go through when formulating an effective methodology (Saunders et al., 2007). According to Bryman (2012) the research onion's usefulness lies in its application flexibility to almost any type of research methodology and can be used in various contexts. The research onion developed by Saunders et al. (2007) has five layers namely the research philosophy, research approach, research strategy, time horizons and data collection methods layers. The research philosophy is the first layer which has to be defined. This leads the starting point of the research approach which is the second layer of the onion. The third step identifies the research strategy to be adopted and the fourth layer identifies the time horizons to be used. The fifth and most inner layer identifies the data collection methodologies to be used. The benefit of the research onion is that it describes the methodological study by illustrating the steps to be taken (Saunders et al., 2007) (Figure 2-1).

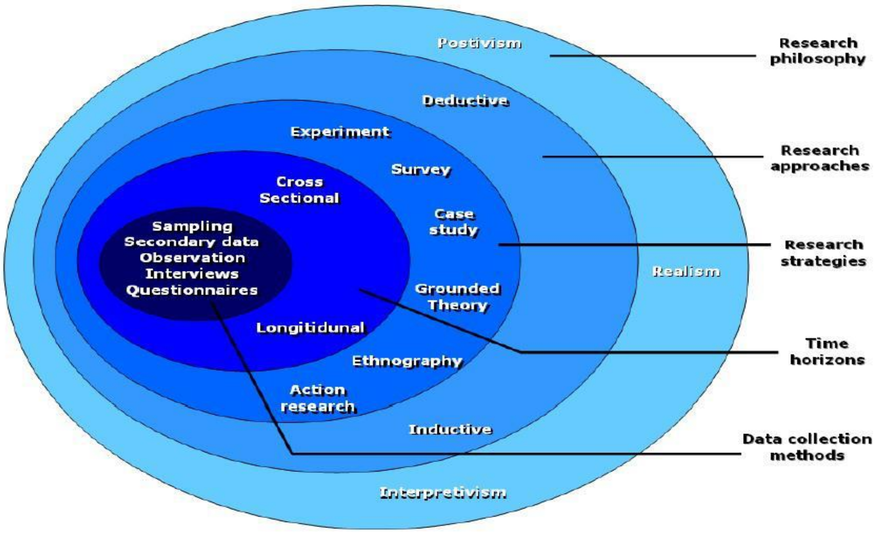

Figure 2-1The Research Process Onion Saunders et al 2007.

The research philosophy provides an underlying characterisation of the nature of knowledge. It discusses a set of beliefs about the nature of the reality being investigated (Bryman, 2012). Through understanding the research philosophy, it becomes possible to explain the characteristics of the assumptions made by the research and how they fit into the methodology. Furthermore, justification for how the research will be undertaken is provided by the assumptions of the research philosophy (Vaishnavi & Kuechler, 2015). The model identifies three primary views relating to research philosophy - positivism, realism and interpretivism. The choice of the research philosophy view to be adopted is defined by the type of knowledge being investigated in the research project (Saunders et al., 2007).

The positivism school of thought originates from natural science and assumes that knowledge is derived from observation and the verification of data received from the study. The interpretivism school of thought focuses on how to investigate social interactions. This approach asserts that social reality is different from natural reality because the subjects of social reality are human beings and their interactions with each other (Tekin and Kotaman, 2013). Unlike positivism, the interpretist approach is subjective. According to Tekin and Kotaman (2013), the knowledge that results from interpretivism is not universally valid, but contextual and restricted to the particular time of the interaction.

Research approaches are plans and procedures of research that cover the activities undertaken from broad assumptions to detailed methods of data collection, analysis and interpretation. There are primarily two research approaches identified, inductive and deductive. The deductive approach, sometimes referred to as the "top-down" approach, works from the general to the more specific (M. N. K. Saunders, Saunders, Lewis, & Thornhill, 2011). The deductive approach may begin with a general theory from which a hypothesis may be developed and tested, and consequently approved or rejected after observation. The inductive approach, also known as the "bottom-up" approach, on the other hand, starts with a specific observation and extends to broader generalisations and theories (Bryman, 2012).

The research strategy is the plan of how the researcher intends to carry out the research (M. Saunders et al., 2007). The research strategy can include a number of different activities, including:

- Interviews;
- Surveys;
- Experimental Research;
- Design Science Research; and
- Case Study Research.

The research strategy is a means by which the research questions can be answered. A well-defined research strategy addresses the research questions and objectives posed by the research (Bryman, 2012).

2.3. Design Science Research

Design research according to Johannesson and Perjons (2012) is not content only that aims to explain, describe and predict but also aims improving the world and creating opportunities through the creation of artefacts. Geerts (2011) states that the purpose of design science is to change existing situations into preferred situations. Design science research is associated with a pragmatic school of thought (Hevner 2007). Hevner (2007) describes pragmatism as a school of thought that studies practical consequences to be vital components of both truth and meaning. This description highlights the purpose of design science research, in providing solutions to problems people in various practices, that is real-world context, encounter using artefacts. Practices consist of human activities performed regularly and are viewed as related to other activities by people participating in them (Johannesson & Perjons, 2012).

A relationship can be established between people, practices, problems and artefacts (Figure 2-2). People participate in practices in which they may encounter practical problems that prevent them from performing their practices adequately. People then make use of artefacts to address the practical problems that they encounter within their practice.

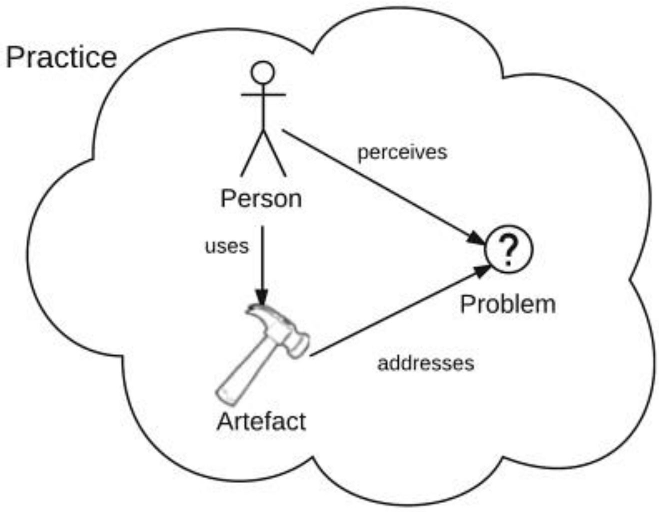

Figure 2-2 People, practices, problems and artefacts (Johannesson & Perjons, 2012)

2.3.1. Motivation for DSR in this Study

DSR will be used as the research strategy in this research. DSR is ideal for Information Technology (IT) research as it focuses on creating innovative artefacts and effective products that are used to solve real-world problems. DSR in Information Systems (IS) is viewed as a problem-solving, performance-improving activity that involves the invention and evaluation of artefacts and their impacts on the overall system (De Villiers, 2005).

This is an ideal methodology for the research at hand because an artefact, the FSA model, will be used to solve existing problems within the after-sales field services domain. The model will be the artefact and theoretical contribution of the research, while the KapCha prototype and its components shall be the development component also referred to as an instantiation. An instantiation is the actual implementation of the artefact to perform a task within a particular environment (De Villiers, 2005).

2.3.2. A Three Cycle View of DSR

The DSR methodology contains an iterative three-cycle process, consisting of the relevance, rigour and design cycles (A. R. Hevner, 2007). Each cycle contains a set of activities that contribute towards the research output and artefact design of DSR. The relevance cycle bridges the gap between the application domain (practice) and the activities of DSR (Johannesson & Perjons, 2012). In the rigour cycle, design science activities are linked to the knowledge base, which consist of scientific foundations, experience and expertise which relate to the research project. The design cycle is at the core of DSR and iterates between the design, development and evaluation of the artefact and the research process. The DSR cycles in this research are as defined by Hevner (2007).

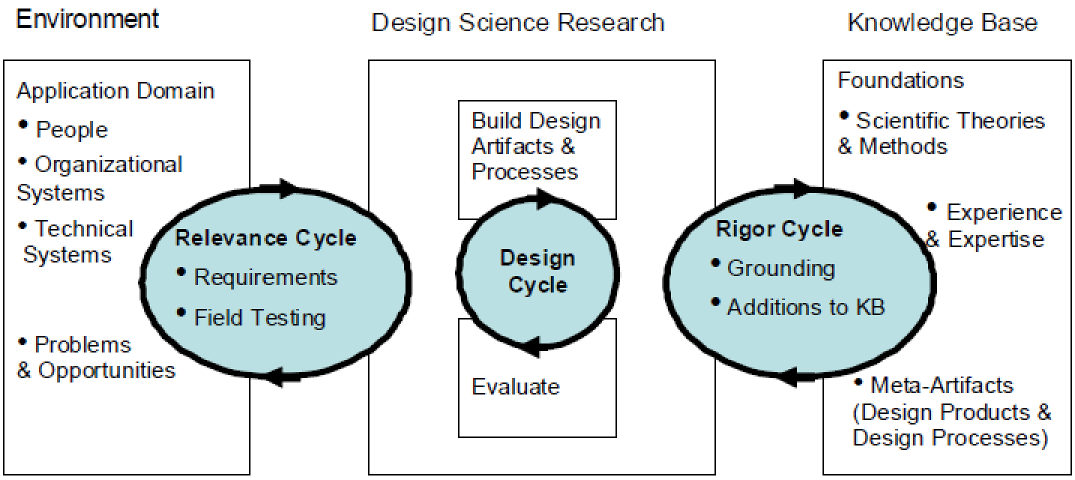

Figure 2-3 Design Science Research Cycles (A. R. Hevner, 2007)

Relevance Cycle

The relevance cycle links design science research and the environments application domain (Figure 2-3). The application domain consists of people, organisational systems and technical systems as well as problems and opportunities within the domain (Hevner 2007). The problems and the opportunities provide requirements for the relevance cycle. The organisational systems and the technical systems are used for the field testing in the relevance cycle. Furthermore, the relevance cycle defines the acceptance criteria for the evaluation of the research artefact before it is returned to the application domain for evaluation and study (Hevner 2007).

The evaluation provides results after testing of the artefact within the application domain. The results from the evaluations may highlight functional deficits or characteristic abilities that may limit the use of the artefact in the real-world. The iterative cyclic nature of the relevance cycle entails a process of iteration of activities and therefore the results from the feedback determine the number of iterations required as part of the DSR project. However Peffers et al. (2007) argue that problems identified in the relevance cycle do not always translate into direct objectives as the design process is one that provides partial and incremental solutions.

Rigor Cycle

The knowledge base basically provides rigor to the research. The rigor is based on the application of the knowledge base, which includes scientific theories and engineering methods, experiences and expertise in the application, and existing artefacts (meta-artefacts) and processes discovered in the application domain. This knowledge base provides the theoretical foundation for a rigorous DSR methodology to be conducted in the Rigor Cycle. The design artefact should expand existing research foundations. Moreover, rigorous research procedures must be used in the development and evaluation of the design artefact. Thus, the Rigor Cycle is able to provide existing knowledge to the research problem, which ensures the artefact is new and innovative. According to Hevner (2007), the research rigor in the DSR methodology is predicated on "*the appropriate selection and application of the theories and methods to construct and evaluate the design artefact*".

Design Cycle

The DSR component is where the artefact is built during the research process, as shown in Figure 2-3. The Design Cycle is the core cycle of any DSR methodology project. This cycle illustrates the iterative nature of the process, whereby the artefacts are built and evaluated in cycles, which rely on existing knowledge or theories. Design artefacts are validated through empirical procedures "*where specific objectives are set, appropriate data is gathered and analysed, and conclusions are drawn*" (Hevner et al., 2004).

Multiple iterations of the Design Cycle in the DSR methodology are performed until an acceptable design is achieved, and only then are contributions outputted into the Rigor Cycle and the Relevance Cycle. Therefore, multiple iterations of the Relevance Cycle and Rigor Cycle are also performed. Another example of multiple iterations is when additional requirements are discovered during the Design Cycle that cause another iteration of the Relevance Cycle and investigated using the existing knowledge base from within the Rigor Cycle. This knowledge provided by the Rigor Cycle for the research problem is then used within the Design Cycle.

2.3.3. Design Science Research Methodology (DSRM) Activities

The Design Science Research Methodology (DSRM) was developed by Peffers et al (2007) to assist DSR researchers on how to conduct their research. In the development of the DSRM Peffers et al. (2007) had three main objectives in mind as follows:

- Create a methodology that is well grounded in existing DSR literature in Information Systems (IS) and related disciplines;
- Provide a nominal process and guidelines for researchers who work on DSR; and
- Provide researchers with a mental model or template for the presentation of DSR outputs.

The DSRM as presented by Peffers et al. (2007) consists of six activities namely the problem identification, objectives definition, design and development of artefact, demonstration of artefact, evaluation of the artefact and communication (Figure 2-4). Each of the activities shall be discussed in further detail in the sections to follow.

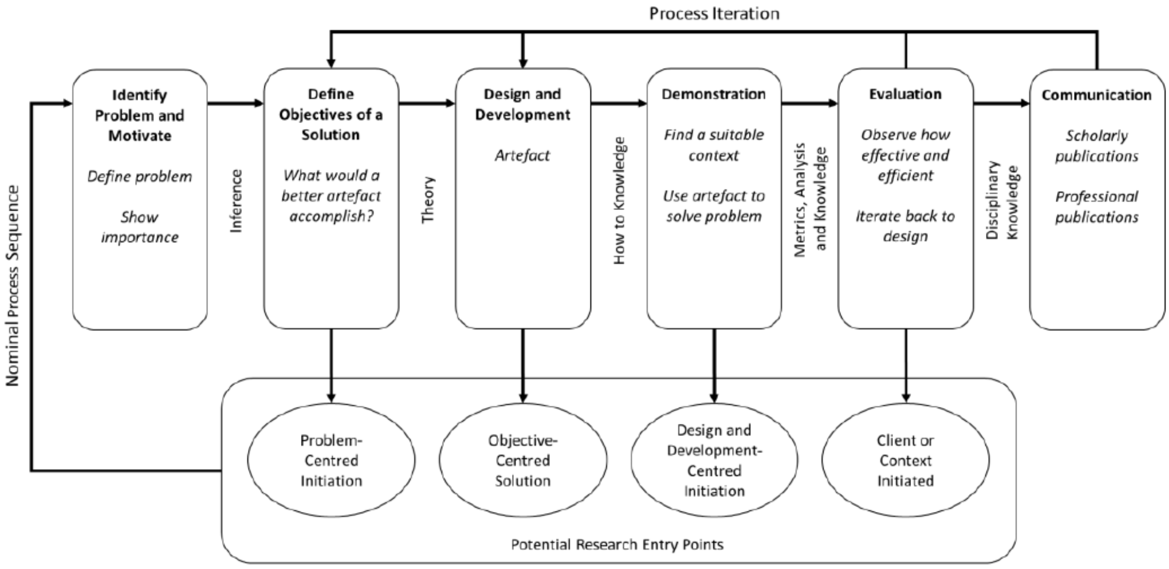

Figure 2-4 DSRM Activities Peffers et al (2007).

The first activity in the DSRM, ***Identify problem and motivate,*** defines the research problem and the justification of the value of a solution. The problem definition is used to develop the artefact that can effectively provide a solution by atomising the problem theoretically in order for the solution to address its complexity. The motivating the problem provides justification to the researcher and the audience of the research as to why the research is being conducted to address the problem. Motivating the value of the solution also aids the researcher in presenting his/her understanding of the problem. The resources required for the first activity include the knowledge of the state of the problem and the importance of its solution (Peffers et al., 2007).

The second activity, ***Define the objectives of a solution,*** defines the requirements that the solution needs to meet. Upon identifying the problems it is necessary to determine the performance objectives of the solution. The objectives are inferred from the problem definition and knowledge of what is possible and feasible (Peffers et al., 2007). The objectives of the artefact can be either quantitative or qualitative. The quantitative objectives identify a desirable solution that would be better than the current ones whilst the qualitative provide a description of how a new artefact is expected to support solutions to problems not previously addressed. The resources required for the second activity include knowledge of the state of the problems and the current solutions, if any, and their efficacy.

In the third activity of the DSRM, ***Design and development***, the artefact of the study is designed and developed. The type of artefact includes constructs, models, methods or instantiations or new properties of technical, social, and/or information resources. According to Peffers et al. (2007) a design research artefact can be any designed object in which a research contribution is embedded in the design. The design activity includes determining the artefacts desired functionality and the architecture and then the creation of the actual artefact. The resources required of moving from the objectives to the design and development include knowledge of the theory that can be brought to bear in a solution.

The fourth activity, ***Demonstration*** of the artefact entails the demonstration of the developed artefact. The demonstration is performed to demonstrate the use of the artefact to solve one or more instances of the problem. This demonstration could involve using the artefact in experimentation, simulation, case study, proof or other appropriate activity (Peffers et al., 2007). The resources required for the demonstration include effective knowledge of how to use the artefact to solve the problem.

The fifth activity is ***Evaluation*** of the artefact and involves the assessment of how well the artefact addresses the problem. This involves observing and measuring how well the artefact supports a solution to the problem. It also involves comparing the objectives of a solution to actual observed results from use of the artefact in the demonstration. It requires knowledge of relevant metrics and analysis techniques. Evaluation of the problem takes different forms depending on the nature of the problem venue and the artefact (Peffers et al., 2007).

The sixth and final activity***, Communication***, communicates the importance of the problem, the artefact, its utility and novelty, rigor of its design, and its effectiveness to relevant audiences such as practicing professionals when appropriate. Researcher may use the structure of this activity to publish research publications of the research process undertaken to complete the research (Peffers et al., 2007). Communication requires knowledge of the disciplinary culture. Table 2-1 shows the DSRM as adapted by Geerts (2008). Geerts (2008) provides a knowledge base that is the resources required for each of the activities. The first column lists the six activities as presented by Peffers et al. (2007).

Table 2-1 Design Science Research Methodology adapted from Geerts (2001).

DSRM Activities	Activity Description	Knowledge Base
Problem identification and motivation	*What is the problem?* Define the research problem and justify the value of a solution.	Understand the problems relevance and its current solutions.
Define the objectives of a solution	*How should the problem be solved?* General objectives such as feasibility and performance are defined as well as the specific criteria that a proposed solution to the problem identified in activity one should meet.	Knowledge of that is possible and what is feasible. Knowledge of methods, technologies, and theories can aid in the definition of the objectives.
Design and development	*Create an artefact that solves the problem.* Create constructs, models methods, or instantiations in which a research contribution is embedded.	Application of the methods, technologies and theories to create one or more artefacts that solve the problem.
Demonstration	*Demonstrate the use of the artefact.* Prove that the artefact works by solving one or more instances of the problem.	Knowledge of how to use the artefact to solves the problem.
Evaluation	*How well does the artefact work?* Observe and measure how well the artefact supports a solution to the problem by comparing the objectives with observation results.	Knowledge of the relevant metrics and evaluation techniques.
Communication	Communicate the problem, its solution and the utility, novelty, and effectiveness of the solution to researchers and the relevant audiences.	Knowledge of the disciplinary culture.

The three cycle view and the DSRM approaches to DSR proposed are similar in that a problem is identified and motivated, the objectives of the solution are determined, the artefact is then developed to solve the identified problem using the objectives determined, and the solution is demonstrated and evaluated in the relevant context. Similar to the three cycle approach to DSR

(A. R. Hevner, 2007), the six activity (Peffers et al., 2007) approach is iterative in nature with each stage dependent on the others.

2.3.4. DSR Guidelines

Hevner et al. (2004) suggested guidelines on how DSR can be conducted within the IS domain (Table 2-2). Guideline 1 highlights the need for research to produce an artefact. The artefact to be produced in this study is a solution to optimise FSA. Guideline 2 states that the research needs to solve an organisational problem that is relevant and will lead to the artefact being used in a real-world situation. In this research the artefact shall be used to optimise FSA within a smart lighting environment. The third guideline highlights the need for evaluation in order to assess the quality of the artefact. Guideline 4 states that DSR needs to provide valuable and useful contributions to the domain. Through the various research methods to be adopted in the research at hand, the problems within FSA shall be determined and the theoretical model is also the envisioned contribution. Guideline 5 states the need to develop and evaluation an application of the artefact. Furthermore, the research fits into an ongoing process of improving FSA by encouraging a continuous search for techniques and technologies that can optimise FSA. A prototype shall be developed and evaluated to assess ability to develop a FSA system based on proposed model.

Table 2-2 DSR Guidelines Proposed by Hevner et al. (2004)

Guideline	Description
Guideline 1: Design as an Artefact	Design science research needs to produce artefact in the form of a model, framework or prototype.
Guideline 2: Problem Relevance	The research needs to solve an organisational problem that is relevant and will lead to the artefact being used in a real life situation.
Guideline 3: Design Evaluation	The quality of the system must be ensured through rigorous testing methods.
Guideline 4: Research Contributions	Design science research needs to provide valuable and useful contributions to the domain.
Guideline 5: Research Rigor	Rigorous development and evaluation of the application needs to take place.
Guideline 6: Design as a Search Process	The design of the artefact needs to be a continuing search process, and all available means should be used to reach the final product.
Guideline 7: Communication of Research	The results of design science research must be presented to both technological experts as well as management.

2.3.5. Research Artefact Types

The creation of artefacts distinguishes DSR from other research paradigms, emphasising the important role of artefacts. There are different types of artefacts just as there are different types of problems within a practice. Johannesson and Perjons (2012) identify four types of artefacts namely constructs, models, methods and instantiations.

Constructs as defined by Johannesson and Perjons (2012) are terms, notations , definitions and concepts that are needed to formulate problems and their possible solutions. Constructs provide definitional knowledge that enable one to explain a practical problem so that it can be understood and changed. Constructs are the smallest conceptual molecules which can be used to understand and communicate information about various phenomena. An example of a construct are concepts of classes in object-oriented programming, functional dependency in relational database theory and methods in Java.

A model is a simplified description of a system or process, to assist calculations and predictions (Stevenson, 2010). Models may also be used as a representation of other objects. Models can be classified into three categories namely descriptive, predictive and prescriptive (Johannesson & Perjons, 2012). A descriptive model represents an existing situation which is used to describe and analyse the problems of the situation. A descriptive model may be used as a pedagogical tool to represent the situation on hand and explain why it is challenging. Models can also be used to describe potential solutions to problems within a practice. Such models are categorised as prescriptive models, which aim at providing solutions to current and future practical problems. The third categorisation of models are predictive models which, as the name implies, are used for forecasting the behaviour of objects and systems.

Methods provide prescriptive knowledge which defines guidelines and processes for how to go about solving problems within a practice. They can prescribe how to create artefacts. Methods can either be formalised - for instance, algorithms - or they can be informal, such as rules of thumb or best practices (Johannesson & Perjons, 2012).

Instantiations are working systems that can be used in a practice. Instantiations implement knowledge from other artefact types for instance a database can embed a database model. Some examples of instantiations are a C# program realising a sorting algorithm or a database for an enterprise systems module.

Table 2-3 Artefact Types (Johannesson & Perjons 2012)

Artefact Type	Description
Constructs	Terms, notations, definitions and concepts that provide definitional knowledge that aids in explaining practical problem in order for it to be understood and addressed.
Descriptive Model	Describe and defines current problem within practice and explains why it is challenging
Prescriptive Model	*Describe potential solutions to problems within a practice*
Predictive Model	Forecast behaviour of system or objects
Methods	Prescriptive Knowledge that defines guidelines and process on how to solve problems within a practice
Instantiations	Working systems used in practice

The artefact that will be produced from this research is a prescriptive model. The artefact shall provide definitions and descriptions that can aid in the optimisation of FSA using the techniques and technologies of IoT. A three-step process of developing a prescriptive model was proposed by Thwink.org (2011). The process consists of:

- The use of a formal process that drives all modelling;
- Diagnosis of why the problem is occurring at the fundamental level before solution hypothesising begins; and
- Creation of the model with the results obtained from the diagnosis in the second activity.

The three-step process of developing the model shall be adhered to through during this research.

2.4. Application of DSRM to this Study

The DSRM has been used in the development of prescriptive models as artefacts that can aid in addressing practical problems in the IS field (Johannesson & Perjons 2012; Marnewick & Labuschagne 2005; Myers & Venable 2014). The research at hand uses the three- cycle view of the DSR methodology as presented by Hevner (2007), in conjunction with the six activities proposed model in the model by Peffers et al. (2007). The DSRM as stated by Peffers et al. (2007) was grounded in DSR literature and aims to aid DSR researchers by providing a process to follow, as well as guidelines for conducting the research. Therefore, the DSRM will be applied and followed throughout this research. The mapping of the two approaches is illustrated in Figure 2-5

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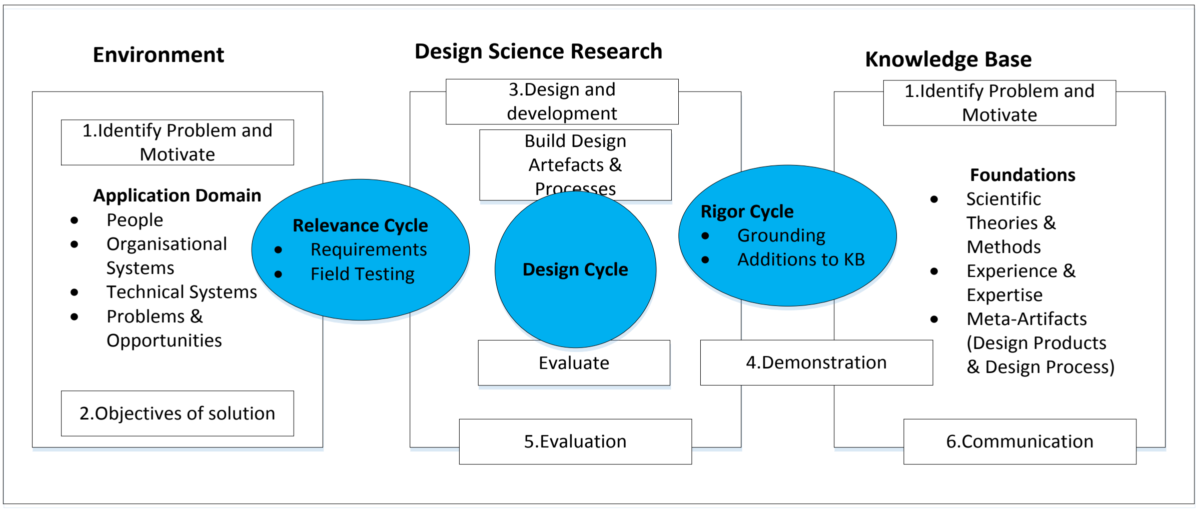

Figure 2-5 Mapping of the Three Cycles View to the Six Activities Approach

The first activity of the DSR methodology, identification of the problem and the motivation shall be report on in Chapters 3 and 4. Chapter 3 shall report on a review of the challenges faced by field service organisations from a literature perspective whilst Chapter 4 shall review the challenges from the application domain. The application of the second activity of DSRM is reported on in Chapter 4 where the objectives of the solution are addressed. The proposed solution in this research is to address FSA challenges and optimise it with the use of an IoT. This need for a solution drives the third activity which is the process of designing the model which is the artefact. The demonstration of the artefact shall be reported on in Chapters 5 and 6. The evaluation of the model as the fifth activity shall be described in Chapter 6. The final activity, communication, shall be addressed in the concluding chapter where the findings of the research shall be consolidated and communicated. The dissertation structure consisting of the DSRM activities, the research questions and research objectives, research methods and the DSR guidelines are shown in Figure 2-6.

	DSRM Activities	RQ's and RO's	Research Methods	DSR Guidelines
Chapter 3	Problem Identification and Motivation	RQ1,RQ2,RQ3,RQ4 RO1,RO2,RO3,RO4	Literature Review Existing system analysis	Guideline 2
Chapter 4	Objectives of Solution Design	RQ5,RQ6,RQ7 RO5, RO6, RQ7	Semi-structured Interviews Case study	Guideline 1 Guideline 2
Chapter 5	Development Demonstration	RQ8 R08	Prototyping	Guideline 1 Guideline 3
Chapter 6	Evaluation	RQ9 RO9	Evaluations	Guideline 5 Guideline 4
Chapter 7	Communication	RQ$_{M}$		Guideline 7 Guideline 4

Figure 2-6 Dissertation Structure Combined with DSR Methodology

A literature study shall be conducted to review the knowledge base for the research domain and therefore aid in understanding the challenges faced field services (Johannesson & Perjons, 2012). The research will also make use of a case study and structured interviews (Peffers et al., 2007).

A smart lighting system maintained by an engineering firm from Port Elizabeth South Africa shall be used as a case study for the research. The engineering firm offers engineering consultancy and systems development services. Amongst the services the firm offers is the service maintenance of a smart lighting system. Optimising FSA by addressing the problems and challenges it faces is the purpose of this study. An interview shall be conducted with a senior engineer at engineering consultancy firm to establish the current operational structure of the system as well as the challenges it faces. Interviews will also be conducted with experts within the field services domain to gain a general understanding of the challenges faced by the sector (Johannesson & Perjons, 2012). An analysis of existing FSA systems will be conducted to determine the industry best practices of an FSA system as well as its requirements (Johannesson & Perjons, 2012).

2.5. Ethical Considerations

Ethics, as defined by Stevenson (2010), is the moral principle governing of influencing conduct. As DSR has emerged as an important research paradigm in the field of information systems (Geerts, 2011; Vaishnavi & Kuechler, 2015; Vial, 2015; Hevner & Chatterjee, 2010), Myers & Venable

(2014) recommend a set of ethical principles to be considered when conducting design science research. They identify four reasons for ethical principles to be considered by design science researchers: the dual potential of IT; the increased attention to teaching ethics in business schools; the increased focus by higher learning education and research institutional boards on the ethical principles to be adhered to by research projects; and the different ethical priorities that design science researchers have compared to other researchers in IS (Myers & Venable, 2014). In this research, only two of the four reasons given will be considered.

Mason (1986) identified the dual potential of information technology. Mason revealed that information systems can enhance or destroy human dignity. Information technologies can improve lives or make them worse. Mason (1986) states that new technologies carry a potential risk, which may arise from the technology being misunderstood or misused after its development, possibly with disastrous consequences. With the emergence of the IoT, the ethical consideration of one's privacy has been noted as one of the main concerns relating to this emerging technological phenomenon (Gubbi,Buyya,Marusic & Palaniswami, 2013; Borgia, 2014). According to Myers and Venable (2014), privacy refers to concerns about how a person reveals information about oneself to others, the conditions under which the information is revealed and the measures to be undertaken to safeguard the information revealed. Privacy is one of the four ethical principles identified by Mason (1986).

A high number of universities and research institutions require researchers to obtain permission from their own ethics review boards or committees in order to conduct research which involves real people or animals. The ethical boards focus on the principles to be adhered to as a research project is conducted by the researcher. There are a number of ethical principles to be considered and some are specific to particular institutions, however the common ones taken into consideration include plagiarism, honesty, informed consent and permission to publish (Myers & Venable, 2014).

Plagiarism is one of the principles most frequently considered by academic institutions. The ideology of plagiarism is that the researcher should not present someone's work as their own without providing appropriate acknowledgement of the author/owner of the work.

Another vital principle is informed consent, and researchers should ensure that participants complete consent forms prior to their involvement in the research. The participants should, to the greatest extent possible, participate freely in the research and be advised that they can terminate their participation for any reason and at any time.

The third principle is that of permission to publish. This principle usually requires the researcher to receive permission from the appropriate person or sample group to publish results based on data collected from them.

The researcher's honesty is important in order for all the previously mentioned principles to be adhered to. For this reason, honesty on the part of the researcher is regarded by many universities and research institutions as an important principle.

Based on the study conducted by Myers and Venable (2014), the ethical principles adopted by research institutional boards (that is, no plagiarism, complete honesty and providing participants with informed consent) should serve as guidelines for the ethical principles to be taken into consideration when conducting DSR. Furthermore, during the development of the artefact, Mason's four ethical issues - privacy, accuracy, property and access - should also act as ethical guidelines.

In conducting this research the principle researcher acquired ethical approval from the NMMU Faculty RTI Committee (Faculty of Science) which is the ethics committee board of the NMMU. Since participants were required to conduct interviews to identify problems within the field services domain, ethical clearance was required for their involvement in this research. Consent forms were given to participants for the interviews conducted. An explanation of this research was given and it was emphasised that participants had the right to withdraw from the interview process. The ethical clearance number for this research is H15-SCI-CSS-011 (Appendix A).

2.6. Summary

The chapter discusses the research methodology and strategies to be used in this research. The DSR methodology shall be used throughout. The DSR methodology presented by Hevner (2007) consists of three cycles - the relevance, rigour and design cycles. Peffers et al. (2007) presented a six activities process approach to DSR to guide researchers and provide them with a structure within which to conduct their research. The three-cycle DSR approach, in conjunction with the DSRM process activities, will be used to govern how this research is conducted. This research will make use of a literature study, a case study and interviews in order to identify the challenges faced by after-sales field service organisations.

The next chapter applies the first activities of the DSR process, which is the problem identification. The chapter focuses on identifying the problems faced by field service organisations. The chapter will also review plausible technology phenomena to address the challenges identified.

Chapter 3. Problems in FSA and an IoT

3.1. Introduction

The preceding chapter discussed the research methodology to be used in this study as well as its application. This chapter reports on the first activity of the DSRM process adapted in this study, namely identify problem and motivate (Figure 3-1), performed within the relevance cycle in theory and real-world.

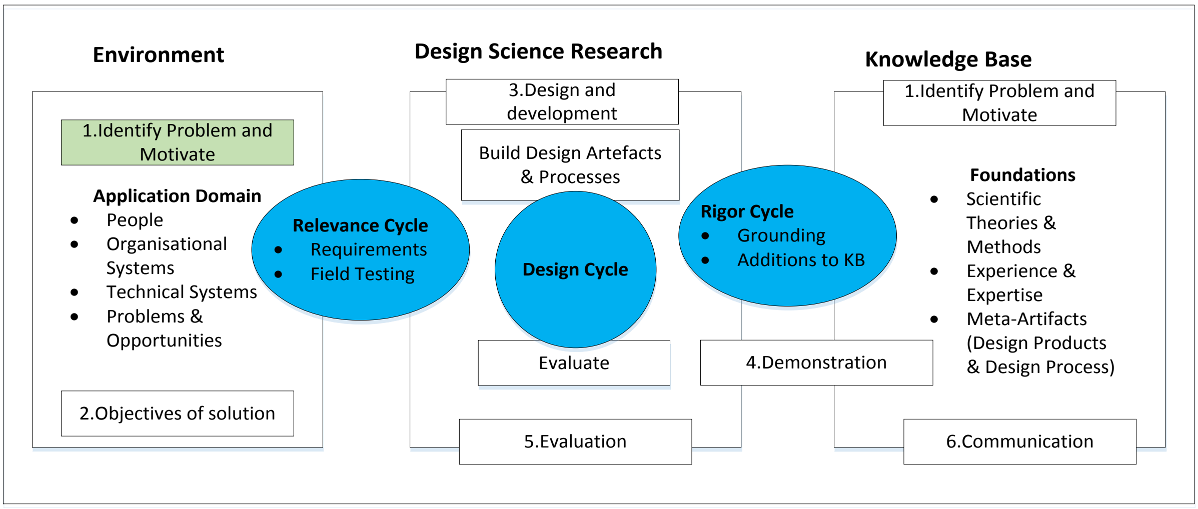

Figure 3-1 Chapter 3 Activities in Adapted DSRM

Explication of the problem shall address the following research questions (Section 1.5):

RQ 1. What problems are faced by field service organisations providing after sales services as identified by literature and within a real-world context?

RQ 2. What technologies can be used to optimise FSA and enable the growth of the IoT?

RQ 3. What are the challenges of the IoT?

The growth of the market of field services has been hampered by problems such as inaccuracy of information and the lack of real-time access to the information (Section 3.2). Technology can be used to optimise after sales field service activities resulting in service effectiveness (Section 3.3). The fulfilment of optimised after sales field services delivery can be measured against the Key Performance Indicators (Section 3.4). The IoT, cloud-computing and cyber-physical systems are technology trends that can optimise FSA (Section 3.5).

The growth of an IoT (Section 3.6) has been driven by technologies such as Big Data analytics, cloud-computing, and data collection tools (Section 3.7). However, the IoT not unlike other technology paradigms is not exempt from challenges, for example security and the management of the voluminous data generated by the billions of devices within the IoT ecosystem (Section 3.8). The different architectures and models of an IoT will be analysed to identify the different components within an IoT (Section 3.9). The application of an IoT can be viewed within the context of the Fourth Industrial Revolution (Section 3.10). Several systems for providing FSA are available using various technologies (Section 3.11). Chapter conclusions will be highlighted in Section 3.12.The full structure of the chapter is illustrated in Figure 3-2.

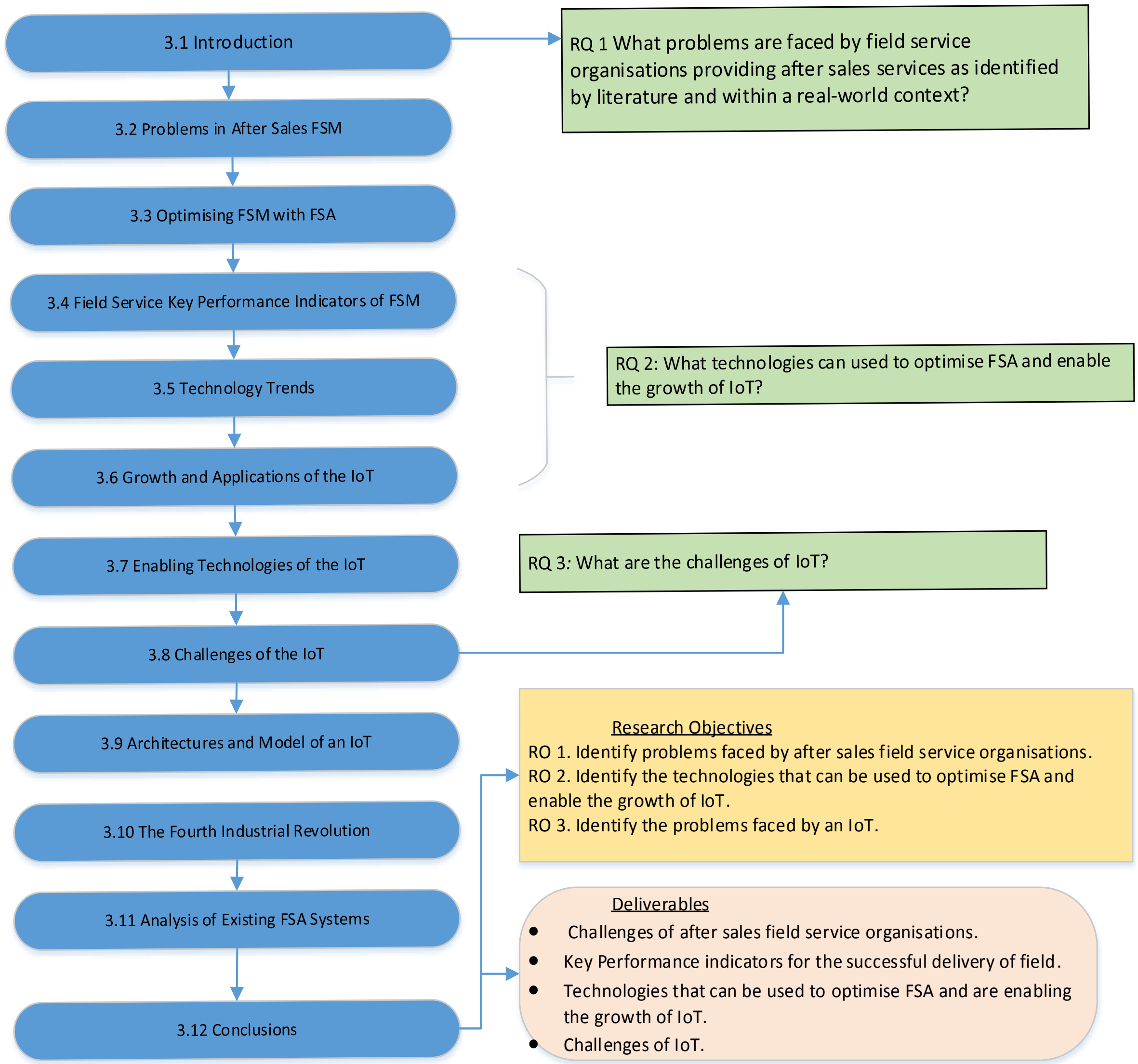

Figure 3-2 Chapter 3 Layout

3.2. Problems in After Sales FSM

As businesses look at cutting costs, increasing efficiency and gaining a competitive advantage, FSM plays an important role in customer satisfaction and loyalty. Competitive advantage can be achieved by businesses providing good product and service support that maximises a customer's after sales satisfaction (Agnihothri et al., 2002). Field service managers are faced with a challenge of managing customer expectations (Agnihothri et al., 2002; Alazraki, 2015). The customer's relationship with an organisation has dramatically changed over the last decade (Alazraki, 2015). Customers expect good after sales services that extend the relationship beyond the initial sale. Customers also expect more preventative measures to be taken by the service provider (Williams, 1998). This highlights the need for delivering superior field service as one of the key factors ensuring customer loyalty which, in turn, ensures continuous revenue. Improved service productivity and customer satisfaction can be achieved by consistent and coherent management of customer expectations, service engagement and employee preparedness (Agnihothri et al., 2002). Therefore, managers of field service organisations are required to consistently achieve positive results. However, FSM has some unique challenges as its operations are spread across vast geographical areas and resources may be distributed in different locations (Sarkar, 2015).

Challenges in FSM within Enterprise Systems may also arise due to the lack of integration of various systems (Schneider et al., 2006). For example, geographical data can be found in Geographical Information Systems (GIS), whilst maintenance-related data and reports are often stored in an Enterprise Resource Planning (ERP) system. Schneider et al. (2006) highlighted the need for the aggregation of data within an ERP system. For instance, electricity data usage captured by an ERP system for a manufacturing plant is stored as an aggregated figure for all work centres within the plant. Aggregated data makes the operational performance monitoring of a single work centre or equipment within the plant difficult.

Field based service organisations have further challenges relating to the role and impact of management of services within the organisation (Agnihothri et al., 2002). The service entity offers services of installation, maintenance or repair (Figure 3-3). The field based service organisation provides these services to a customer at the customers' site (on-site service) or from a remote location. To address these challenges, Agnihothri et al. (2002) suggest a framework that leverages technology in order to improve field service operations .(Figure 3-3) The framework identifies the key components which are employees, the company and customers of a service organisation and how technology impacts those components.

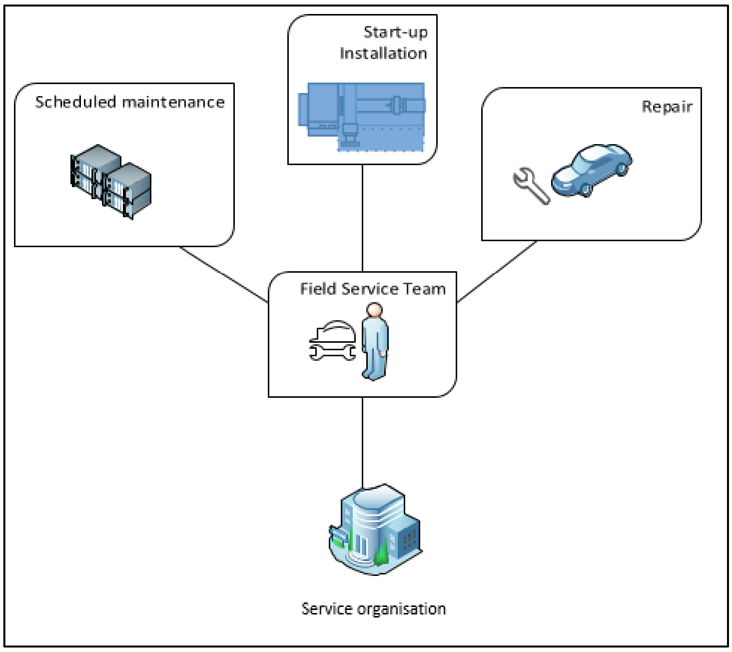

Figure 3-3 Field Service Activities (Authors Own Construct)

There has been an increase in the number of organisations providing field services as organisations become more customer-centric (Lehtonen et al. 2012; Sarkar 2015). A customer's product purchase decision is not only influenced by the product's value but also by the service support available after the sale of the product. The increase in the number of organisation offering field services poses management within the service organisation to continuously seek innovative solutions. Lele and Karmarkar (1983) point out how the provision of a good product support plays an important role in a business gaining competitive advantage. Technology advancements are driving innovation in providing better after-sales field services in order for organisations to gain a competitive advantage (Agnihothri et al., 2002). Field service organisations can attain a competitive advantage by automating their operations. Field Service Automation (FSA) is the term used to refer to the automation of FSM (Alazraki, 2015).

Management of downtime is important to both the organisation providing the service and the customer (Behara & Lemmink, 1997; Knotts, 1999). From the customer's perspective, that is the organisation undergoing downtime, the downtime period has operational implications such as reduced productivity levels, delayed delivery of services to the organisation's clientele. It is therefore imperative that downtime is kept minimal period. Service providers have to adequately manage downtime in order to satisfy its customers and by doing so efficiently they may gain a competitive advantage.

The two main characteristics that define a field service call are the response time and the machine downtime (Agnihothri et al., 2002). The service provider typically evaluates its system by the response time which is the sum of service call queue time and technician travel time to reach the customer's site, but does not include repair time. The time a call is in the queue, in turn, depends of the rate of call arrivals, travel and repair times, and technician scheduling. However, from the customer's perspective, the total machine downtime is of significance. Downtime would not only include how quickly their problem was diagnosed and repaired, but also is an indicator of the spare part's management process of the service firm. Knotts (1999) gives a more detailed explanation of downtime and identifies four phases of downtime, namely:

- Problem detection phase: This is when the customer recognises that there is a problem with the equipment or when the equipment breaks down.
- Gaining access phase: This is the time taken by the field service team to gain access to the client's site.
- Diagnosing the problem and recognising the cause: Upon arriving on-site, the field service team will have to find the problem and determine its cause. In some cases, the service team can be aware of the problem before arriving on-site if they make use of remote monitoring systems, which can eliminate or shorten the time taken to complete this phase.
- Corrective measures: This is the rectification phase of downtime. The field service team resolves the problem during this phase. In the event that the problem cannot be rectified in one visit, the service team may have to make a return visit, in which case this phase is prolonged.

Downtime can be managed by either corrective or preventative maintenance (Lehtonen et al., 2012; Vans, von Mayrhauser, & Somlo, 1999; Williams, 1998). Corrective maintenance occurs when the machinery breaks down. Corrective maintenance includes activities undertaken to diagnose and rectify a fault so that the failed machine, equipment or system can be restored to its normal operational state (Vans et al., 1999). Preventative maintenance entails returning the machine, system or equipment to its normal operable state before failure or breakdown (Williams, 1998). Ideally, preventative maintenance is undertaken in order to prevent equipment failure before it occurs. Preventative maintenance can be achieved by means of scheduled maintenance or condition based maintenance (CBM). Scheduled maintenance is conducted at regular intervals agreed upon between the service provider and the customer, usually by means of a signed contractual agreement (Williams, 1998). CBM makes use of remote monitoring systems that monitor and analyse data on product use and performance. Any abnormality in operational performance is detected and the service team takes the necessary measures to return the machine, equipment or system back into a normal operable state. In summary problem detection takes in place in three ways a customer call after system failure, scheduled maintenance by means of a contractual agreement between a customer and the service provider and operational performance monitoring using CBM. By identifying the most efficient source of problem detection, field service providers can determine strategies to ensure that downtime recognition and rectification are achieved with optimal efficiency.

Access to information in real time aids organisations in optimising FSM (Lehtonen et al., 2012; McNeill et al., 2013; Petrakis et al., 2012). Lehtonen et al. (2012) identify the lack of real-time access to information to both dispatchers and service technicians as a problem faced by field service organisations. Real-time access to information can minimises access to a client location and the on-site time spent servicing a clients' request (Agnihothri et al., 2002; Lehtonen et al., 2012). With the use of real-time information, the service team can locate the clients' location using GPS services, in the event that the service team may already be in the field attending to another client. Real-time access to the clients' location eliminates the need for the service team to return to the service provider's facilities in order to get information about a new client's request (Petrakis et al., 2012), thereby optimising the scheduling element of FSA. The availability of accurate information on-site is another problem that impacts field service delivery. In a case study conducted by Lehtonen et al. (2012), it was reported that service teams could not provide a service due to missing spare parts. The main reason identified for the wrong spare parts was due to the inaccurate information on the spare parts to be taken to a client's at the time of repair or maintenance. Table 3-1 provides a summary of the problems faced by after-sales organisations. The problems have been categorised as market, managerial or technical based on the description. The market related problem shall not be considered in the context of this study though identified as it is out of scope.

Table 3-1 Summary of Problems in FSM

Problem	Type	References
PB 1: Increase in competition	Market	Lehtonen et al. (2012); Sarkar (2015)
PB 2: Management of customer expectations	Managerial	Agnihothri et al. (2002)
PB 3: Management of geographical dispersed clients		Sarkar (2015)
PB 4: Lack of integration between enterprise systems and FSM systems	Technical	Schneider et al. (2006)
PB 5: Access to real-time information		Lehtonen et al. (2012); Petrakis et al. (2012)
PB 6: Management of field service activities	Managerial and technical	Agnihothri et al. (2002)
PB 7: Down-time management		Agnihothri et al. (2002); Knotts (1999)
PB 8: Inaccurate information		Lehtonen et al. (2012)
PB 9: Availability of resources on site		Lehtonen et al. (2012); Petrakis et al. (2012)

3.3. Optimising FSM with FSA

The use of FSA to optimise FSM has been reported on by researchers (Agnihothri et al., 2002; Rotter, 2016). FSA integration of functions within the service organisations can lead to lowered costs of delivery and personalised service delivery (Agnihothri et al., 2002). Cost reduction and personalised service delivery for customer's results in service effectiveness. Service effectiveness aims at improving service productivity and improving customer satisfaction through managing customers service expectations, service engagement and employee preparedness. Agnihothri et al. (2002) developed a model for service effectiveness called the Diplomacy-Preparedness-Engagement Aided by Technology (DPEAT) model presented (Figure 3-4). At the top of the model is technology and the three vertices of the foundation of the service organisation which are the customers, the company and the employees. The three axes define the primary relationships, namely:

- Customers-to-company;
- Company-to-employees; and
- Customers-to-employees.

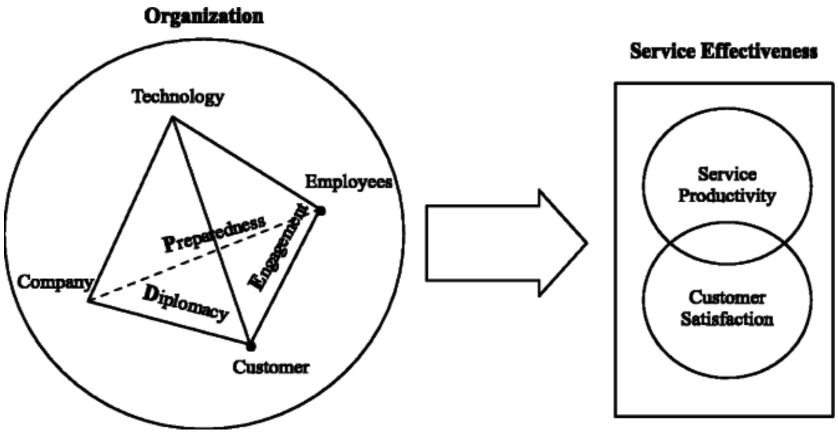

Figure 3-4 DPEAT Model (Agnihothri et al., 2002)

The DPEAT model focuses on the impact technology has on the relationships of the three pillars of the service organisation which are the company, customer and employees. Diplomacy addresses the ability of the organisation to strategically manage the relationships with its customers through the management of their expectations. With the aid of technology this is achieved through an integrated Customer Relationship Management system. The preparedness of employees focuses on ensuring field technicians are well trained and adequately prepared to meet customer needs. Preparedness can be enabled with the use of mobile technologies to provide service teams with customer data such as service history and customer service contract details.

Engagement occurs when the service team interacts with the customer. The deployment of technology within a service organisation to manage its operations can move a service organisation from low productivity to high whilst meeting customer's levels of expectations (Agnihothri et al., 2002). According to the model the effectiveness of service delivery is based on how well the three relationships are managed by FSA techniques. The success of FSM can be determined by evaluating its Key Performance Indicators (KPIs). Field service KPI's shall be discussed in the next section.

3.4. Key Performance Indicators of FSM

Measuring the performance of a service organisation is key in establishing whether it is overcoming challenges within the industry as well as maintaining a competitive advantage. KPIs are quantifiable metrics that reflect the performance of an organisation in achieving its goals and objectives (Bauer, 2004). KPIs further provide a set of common standards that assist an organisation's collaboration and coordination in the execution of tasks (Bauer, 2004). Parmenter

(2015) describes KPIs as operational critical success factors that are the key driving force behind performance measures. It is therefore imperative to establish the KPIs within FSM in order to establish the performance measures that need to be met in order to optimise field services. In this section a selection of KPIs identified through a review of literature, web articles and podcasts of interviews with FSM experts shall be discussed.

The management of downtime is regarded as the core KPI to be considered by service organisations (Behara & Lemmink, 1997; Gaiardelli, Saccani, & Songini, 2007; Lehtonen et al., 2012). The measurement performance during downtime can be divided into two categories, that is, response time and on-site average repair time. Response time can be used to determine how quickly service technicians respond to service calls. According to Michael Israel in an interview with MSI Data magazine (Rotter, 2016) the quicker technicians respond the more service calls they can address in specific period of time. The average travel time can be optimised through the use of intelligent systems that make use of Artificial Intelligence (AI) mechanisms to establish which technician is closet to a client's site. Furthermore, by equipping service technicians with mobile devices whilst in the field, they can get real-time access to clients' locations and service technicians availability. By evaluating the average on-site repair time service organisations can address the training needs of service technicians (Behara & Lemmink, 1997). If the average repair time taken a service technician in rectifying a particular problem is longer than that of other technicians working on a similar problem the training needs of the technicians performing below average can be identified (Chaniotakis, Lymperopoulos, Rigopoulou, & Siomkos, 2008).

The service technician is usually the first point of interaction a client has with an organisation and in most circumstances is the ambassador of the particular organisation (Agnihothri et al., 2002). The efficient utilisation of service technicians is another KPI that has been identified by Rotter (2016). By tracking the utilisation and productivity of service technicians organisations are able to identify their most valuable employees. The employees with high productivity can be rewarded and used as a benchmark in setting performance standards for an organisations field service technicians.

Another KPI to consider is the effective utilisation of labour and inventory resources within a service organisation (Belvedere, Grando, & Bielli, 2013). The monitoring of inventory that is unused due to inaccurate specification of the required parts can aid the organisation in determining what service tools are required for the successful execution of tasks. Also, an increase in the acquisition of emergency inventory to meet customer needs highlights the organisations inability to equip technicians with the appropriate tools to execute tasks (Belvedere et al., 2013).

The percentage of maintenance contracts being renewed and new clients being signed can also be used to assess the organisation's service delivery (Lehtonen et al., 2012; Petrakis et al., 2012). An increase in the renewal of service contracts can be achieved by ensuring preventative maintenance is a priority in service delivery. The higher the percentage ratio in favour of preventative maintenance as opposed to reactive maintenance is key in ensuring a service organisation keeps its customers satisfied.

The KPIs identified can be used to determine areas within the business that need to be reviewed as well as helping an organisation to measure the performance of its operations. Table 3-2 provides a summary of the KPIs discussed.

Table 3-2 KPIs for FSM

KPI	Source
Low average response time	Agnihothri et al. (2002); Belvedere et al. (2013)
Low average on-site repair time	Agnihothri et al. (2002); Chaniotakis et al. (2008)
High levels of labour and inventory resource utilisation	Belvedere et al. (2013)
Low percentage of unused service parts	Rotter (2016a)
High percentage maintenance contract renewals	Rotter (2016a)
Low emergency parts order costs	Alazraki (2015); Rotter (2016a)
Higher preventative to reactive maintenance ratio	Chaniotakis et al. (2008); Williams (1998)

3.5. Technology Trends

FSA has been driven by the latest advances in technologies such as cloud-computing, mobile computing, advances in communication technologies as well as the management of data generated from multiple devices connected to the Internet. In this section an evaluation of technology trends that have an impact on field services shall be discussed in order to determine which possible technologies can aid in the optimisation of field service organisations.

3.5.1. Cloud-Computing

Cloud-computing was defined by the National Institute of Science and Technology (Mell & Grance, 2011) as a model for enabling ubiquitous on-demand computing services through network access for example servers, storage applications, and services. Cloud-computing services can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell & Grance, 2011). Cloud-computing services can be described as three service models namely Platform-as-Service (PaaS), Software-as–a–Service (SaaS) and Infrastructure–as–a–Service (IaaS) (Buyya, Broberg, & Goscinski, 2010).

SaaS is the provision of applications running on a cloud to a consumer by a provider (Botta, De Donato, Persico, & Pescapé, 2016; Mell & Grance, 2011). The applications are accessible from various client devices through either a client interface, such as a web browser or a program interface. The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user- specific application configuration settings (Buyya et al., 2010).

PaaS provides the capability for the consumer to deploy applications he/she as acquired or created onto the cloud infrastructure. The consumer creates the applications using languages, libraries, services, and tools supported by the cloud services provide (Buyya et al., 2010). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, or storage, but has control over the deployed applications and possibly configuration settings for the application-hosting environment.

The capability provided to the consumer to provision processing, storage, networks, and other fundamental computing resources is referred to as IaaS. IaaS allows the consumer to deploy and run arbitrary software, which can include operating systems and applications(Mell & Grance, 2011). The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications; and possibly limited control of select networking components such as host firewalls (Botta et al., 2016). According to Mell and Grance (2011), cloud-computing has the following essential characteristics:

- On-demand Self Service: users can demand their services and use them without any human interaction with service provider.
- Broad network access: users access the cloud services from anywhere and at any time by using different types of platform (such as mobile phones, laptops and tablets).
- Resource pooling: computing resources are pooled into the cloud to provide services to multiple users in the same time.
- Pay-Per-Use: cloud-computing enables users to request the amount of required resources and be billed based on the time and the resources requested.

- Virtualisation: physical resources are hidden from users when using cloud services.
- Multitenancy: a cloud provides services to multiple users at the same time.
- Scalability: the infrastructure of cloud-computing is very scalable. The user has the illusion of infinite availability of computing resources on demand.
- Reliability: is achieved in cloud-computing by using multiple redundant sites.

Cloud-computing has nearly unlimited capabilities in terms of storage and processing power and has become a much more mature technology over the last decade.

3.5.2. Cyber-Physical Systems

Cyber-Physical Systems (CPS) are automated systems that enable the connection of the operations of physical reality with computing and communication infrastructures (J. Lee, Bagheri, & Kao, 2015). Unlike traditional embedded systems, which are designed as stand-alone devices, the focus in CPS is on networking several devices (Jazdi, 2014). CPS fits into the trend of having information and services everywhere at hand, and it is inevitable in the highly-networked world of today.

A CPS consists of a control unit, usually one or more microcontroller(s), which control(s) the sensors and actuators that are necessary to interact with the real world, and which processes the data obtained (Jazdi, 2014). These embedded systems also require a communication interface to exchange data with other embedded systems or a cloud. The data exchange is the most important feature of a CPS, since the data can be linked and evaluated centrally, for instance. In other words, a CPS is an embedded system that is able to send and receive data over a network.

Embedded systems, such as smartphones, cars and household appliances, are becoming an inseparable part of modern life. Nevertheless, it is possible to control only a few of them remotely. It is desirable for a person to turn on the heating system on the way back home, so that the house is already warm upon arrival. Coffee machines can start brewing the coffee in the morning while one is still in bed, in order to shorten the waiting time. Remote access to process data can also be used for the maintenance of these systems. The information from the remote diagnostics helps the service personnel bring the right tool and spare part. The system can order its spare parts by itself with the help of a corresponding communication infrastructure. A CPS has two main functional requirements (Jazdi, 2014):

- The advanced connectivity that ensures real-time data acquisition from the physical world and information feedback from the cyber space;

- Intelligent data management, analytics and computational capability that constructs the cyber space.

Lee et al (2015) argued that the two functional requirements are abstract and not specific enough for implementation purposes and therefore developed a 5C architecture for a CPS system (Figure 3-5). The 5C CPS architecture provides a step-by-step guideline for developing and deploying a CPS. The 5C defines, through a sequential workflow manner, how to construct a CPS from the initial data acquisition, to analytics, to the final value creation. The first level defines the functions and attributes of acquiring accurate and reliable data from the machines and their components. The second level, Data-to-Information conversion involves the inferring of information from the data collected at the first level. The cyber level acts as central information hub in the architecture. Information gathered from the different machines is analysed to extract additional information that provide better insight over the status of individual machines. The cognition level is the knowledge repository for the monitoring of the machines. It presents the acquired knowledge to expert users to aid in decision making. The configuration level provides the feedback from cyber space to physical space and acts as administrative control to make machines self-configure and self-adaptive.

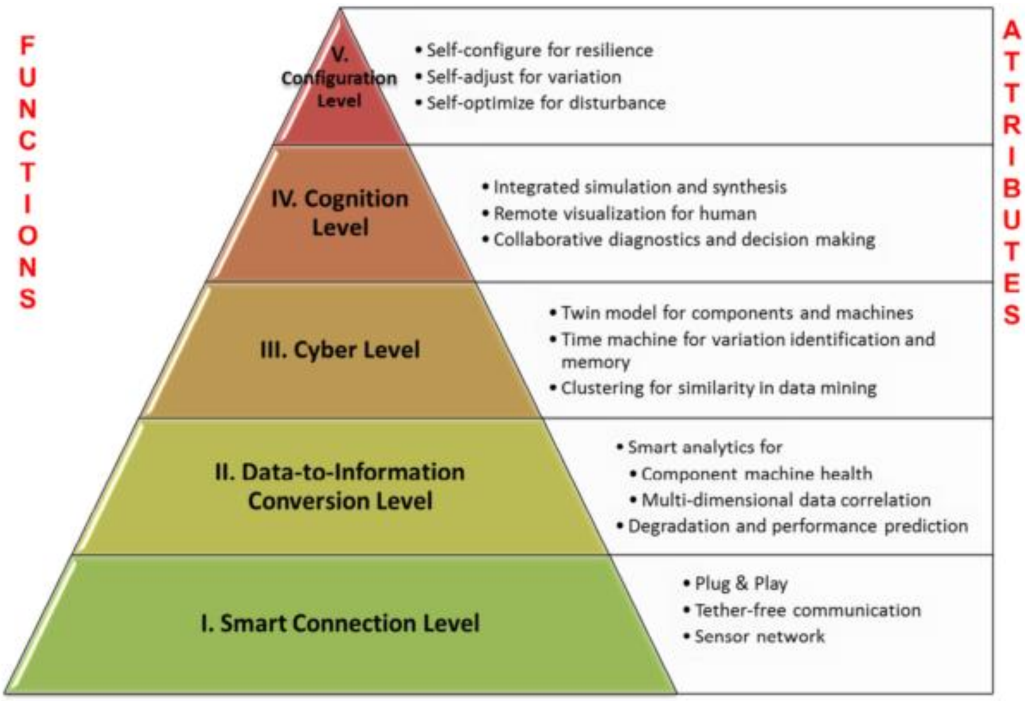

Figure 3-5 5C CPS Architecture (Lee et al., 2015)

3.5.3. The IoT

Through various technology advances human society is moving towards an era of always being connected. As a result of this connectivity amongst humans there has been a need to connect with objects, referred to as smart objects, which impact our daily lives. The need for connection with objects has led to the coining of a new concept known as "Internet of Things" (IoT). IoT describes a vision where objects are connected to the internet, or become part of it, and are accessible through a network providing their location and status (Coetzee & Eksteen, 2011). Bi et al. (2014) define IoT as an extension of the Internet which provides real time information about objects in the physical world and leads to innovative services with high efficiency and productivity. Kortuem, Kawsar, Fitton and Sundramoorthy (2010) describe IoT as a decentralised system of smart objects with sensing, processing, and network capabilities.

The definition of "things" covers a wide range objects. A thing in IoT is anything that is connected to the internet that has a unique identification that provides data and information, and sometimes services. The types of things ranges from personal devices we carry around such as mobile phones and tablets to environmental objects embedded with sensors and communication devices such as motor vehicles and our homes, that is, smart homes(Coetzee & Eksteen, 2011). In 2005 the International Telecommunications Union (ITU) described four dimensions of IoT, that is:

- Object identification (tagging things);
- Sensors and wireless sensor (feeling things);
- Embedded systems (thinking things); and
- Nano technology (shrinking things).

The first step in order to enable an object to become a "thing" in an IoT is its provision of a unique identification. Open standards such as Internet Protocol version 6 (IPv6) enable the provision of unique addressing schemas for objects in IoT (Coetzee & Eksteen, 2011). Secondly, it is important to enable the object to communicate and therefore it should be provided with network communication capabilities so it can connect to a network in order to transmit data. The third step would be providing the object with sensors so that it can transmit data about its status. Optionally some objects have embedded systems which enable them to not only transmit data but also receive data and be controlled. These systems enable the object to provide intelligence thus referred to as "thinking objects".

Miorandi et al. (2012) report on the various visions that categorise IoT into three viewpoints, namely things oriented, internet oriented and semantic oriented. A things oriented approach focuses on objects and on finding a paradigm able to identify and integrate them. On the other hand, the internet oriented approach lays emphasis on the networking paradigm and on developing an IP protocol that provides an efficient means of connection and communication between devices, while simplifying IP so that it can be used on devices with limited capacity. The semantic oriented categorisation aims to use semantic technologies which describe objects and manage huge amounts of data generated by an IoT.

Although technology advances enables the possibility of an IoT it is the application of the IoT which is driving its evolution (Borgia, 2014; Fleisch, 2010). The potential social, environmental and economic impact that the IoT has on the decisions we make and actions we take is its main driving force. For example having accurate information about the status, location and identity of things which are part of our environment opens the way for making smarter decisions. Fleisch (2010) argues that the IoT is important in every value chain and identifies seven main application value drivers for the IoT, namely:

- ***Simplified manual proximity trigger*** – things can communicate their identity when they are moved into the sensing space of a sensor. Once the identity is known and communicated, a specific action or transaction can be triggered.
- ***Automatic proximity trigger*** – an action is triggered automatically when the physical distance of two things drops below (or passes) a threshold. The identity of the thing is known, which when combined with the physical location and action allows for better processes.
- ***Automatic sensor triggering*** – a smart thing can collect data via any type of sensor including temperature, acceleration, orientation, vibration and humidity. The thing senses its condition or the environment it resides in. It then sends the data to a storage and analysis server where information can be derived to aid strategic decision making.
- ***Automatic product security*** – a thing can provide derived security (information) based on the interaction between the thing and its cyberspace representation (e.g. a QR-code containing a specific URL pointing to relevant information).
- ***Simple and direct user feedback*** – things can incorporate simple mechanisms to provide feedback to a human present in the environment. Often these feedback mechanisms are in the form of audio (audible beep) or visual (flashing light) signals.

- ***Extensive user feedback*** – things can provide rich services to a human (often the thing is linked to a service in cyberspace through a gateway device such as a smartphone). Augmented product information is a good example of extensive user feedback.
- ***Mind changing feedback*** – the combination of real world and cyberspace might generate a new level of changing behaviours in people. One possibility is changing the driving behaviour as sensors in the vehicle communicate driving patterns to an outside agency.

Chui, Loffer and Roberts (2010) give another view of the application classification of the IoT. They classified the IoT into two broad categories: 1) Information and analysis and 2) Automation and control.

In Information and analysis, decision making services are enhanced by receiving better and more up to date information from networked elements in the environment, allowing for a more accurate analysis of the current status-quo. This category applies to tracking, for example. products in a logistics value chain, situational awareness (for example, sensors in infrastructure or environmental conditions such as temperature and moisture) through real time event feedback and sensor-driven decision analytics which introduce concepts revolving around longer term, more complex planning and decision making such as user shopping patterns in malls and stores.

Automation and control implies acting on outputs as received from processed data and analysis. Process optimisation in industry is a promising application. A typical example would be where sensors measure the composition of a chemical compound, communicate it to a central service, where after the service analyses and accordingly adjust actuators to fine tune the composition. Optimised resource consumption can potentially change usage patterns associated with scarce resources. Sensing and communicating the consumption of energy in households or data centres allow owners to adjust or load balance their usage to off-peak times with potentially lower costs.

Table 2-1 summarises the key features of the technology trends identified. IoT encompasses the other technologies identified and therefore is the suggested technology trend to be used to facilitate the addressing of the challenges of IoT.

Table 3-3 Technology Trends Summary

Technology Trend	Key features of technology	Source
Cloud-Computing	Provision of on-demand computing services through network access for example servers, storage applications, and services.	Botta et al. (2016); Mell and Grance (2011); Buyya et al. (2010)
CPS	Real-time data acquisition from the physical world and information feedback from the cyber space. Intelligent data management, analytics, and computational capability	Chen et al. (2012); Jazdi (2014); Lee et al. (2015)
IoT	Connection of objects onto the Internet Provision of real-time information about smart objects Information gathering and analysis Automation and control capabilities	Bi et al. (2014); Coetzee and Eksteen (2011); Chui et al. (2010); Fleisch (2010); Kortuem et al. (2010)

3.6. Growth and Applications of the IoT

Since its inception as a medium of communication, the Internet has undergone various forms of transformation. It has grown from the Advanced Research Projects Agency Network (ARPANET), used as a means of connecting various learning institutions, to Web 2.0 technologies which enable connection between individuals, from remote locations of the world, to businesses and learning institutions (Chui et al., 2010). The type of information transferred over the Internet has also evolved. Organisations use the Internet as a means of transferring business data, and with the dawn of social media, the Internet is widely used as a means of connecting people. The Internet is now going through another transformation as objects connect to the Internet as a communication and data transfer platform. The addition of objects onto the Internet, with the intention of creating a bidirectional means of data transfer, is at the heart of the IoT. The extension of communication with the objects we use has created a lot of hype within industry and academia due to the endless possibilities that this new phenomenon creates, as clearly illustrated in Gartner's Hype Cycle reports from 2012 (Figure 3-6) to 2015 (Figure 3-7). A Hype Cycle is a way to represent the emergence, adoption, maturity and impact on applications of specific technologies (Gartner Inc., 2015). It has been forecasted that the IoT will take five to ten years to be adopted by the market. The evolution of the IoT from a vision to a recent reality has been accelerated, with various organisations investing in projects in order to make it a reality. This trend is reflected in the IoT's rise in Gartner's hype chat (Figure 3-7).

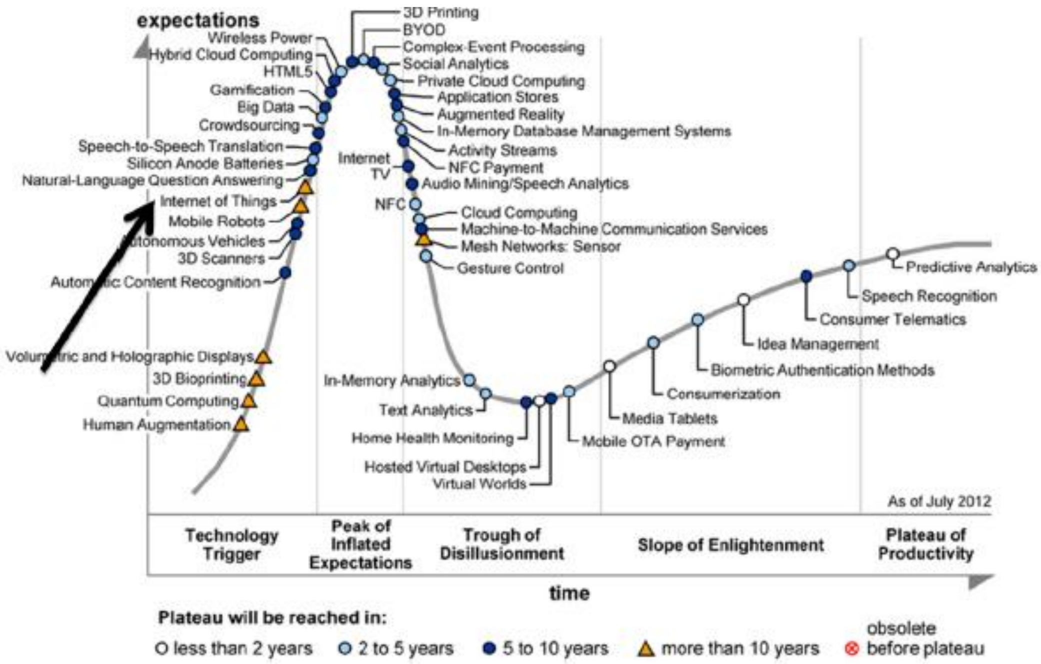

Figure 3-6 Gartner Hype Cycle Emerging Technologies 2012

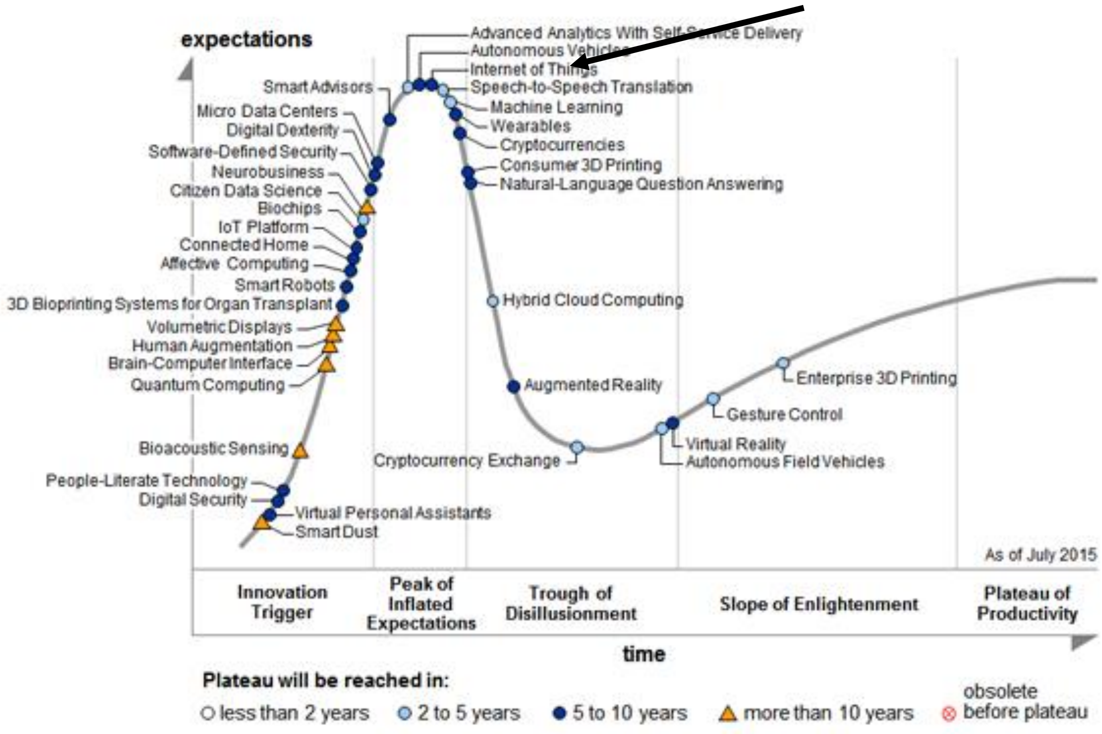

Figure 3-7 Gartner Hype Cycle Emerging Technologies 2015

The popularity of different technology paradigms varies with time. The web searches popularity index on technology paradigms, as measured by the Google search trends during the last 10 years for the terms Internet of Things, Wireless Sensor Networks and Ubiquitous Computing (Figure

3-8). As can be seen, since 2010 the IoT's search volume has consistently increased, with a falling trend for cloud-computing.

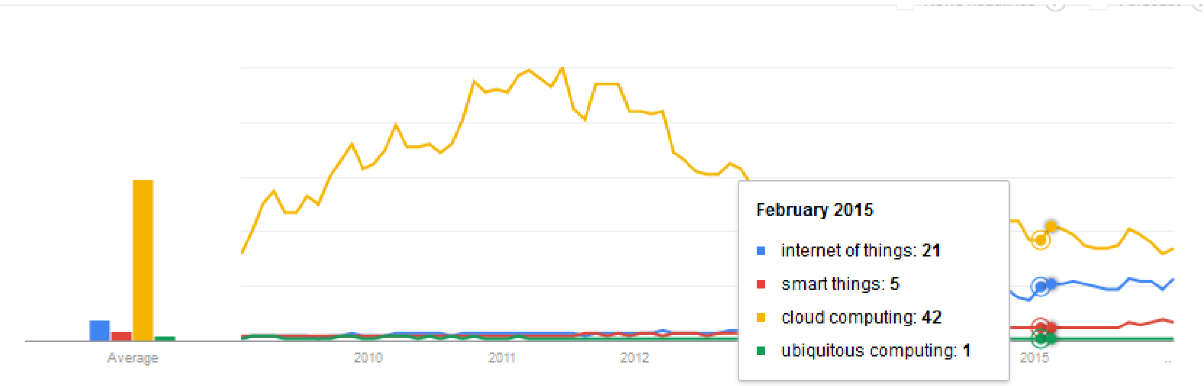

Figure 3-8 Google Search Trends since 2010 for terms Internet of Things, Smart Things, Cloud-computing, Ubiquitous-computing

Although there has been a growing interest from scientific research as well as marketing and sales strategies within business organisations on the IoT paradigm no clear and explicit definition has been established. According to Borgia (2014) this gap is due to the different underlying visions with which business organisations, research centres and academic institutions view this paradigm. Furthermore, the meaning of the term continuously evolves over time due to changes in the technology and the ideas behind it.

3.6.1. Defining the IoT

Kevin Ashton, regarded as the founder of the IoT, coined the term IoT at a presentation held at Procter and Gamble in 1999 (Ashton, 1999). He envisioned a world where the Internet by means of RFID and sensor technology could observe, identify and provide real-time feedback, which could have huge potential to enhance the comfort, security and control of human lives. In 2005, the International Telecommunications Union (ITU) (2005) published their first article on the subject and defined it as follows: "*a new dimension has been added to the world of information and communication technologies (ICTs): from anytime, any-place connectivity for anyone, we will now have connectivity for anything. Connections will multiply and create an entirely new dynamic network of networks – an Internet of Things*" (International Telecommunications Union, 2005). The vision suggested by the ITU expanded the types of objects beyond RFIDs to include different objects which could have unique identities. Since then, the IoT has been defined by various researchers in different ways and in various contexts (Borgia, 2014; Coetzee & Eksteen, 2011; Kortuem et al., 2010; Miorandi et al., 2012).

According to Borgia (2014), the IoT links uniquely identifiable things to their virtual representations on the Internet by their identity, status and location. The linking of the things ensures that accurate and appropriate information may be accessed in the right quantity and condition, at the right time and place, and at the right price. Coetzee and Eksteen (2011) described the IoT as a vision where every object is uniquely identified and accessible to the network, its position and status known, and where services and intelligence are added to this expanded Internet, fusing the digital and physical worlds, and ultimately impacting on our professional, personal and social environments. The IoT also includes the set of supporting technologies that enable a global network of interconnecting smart objects that are able to communicate by means of extended Internet technologies (Miorandi et al., 2012).

A fundamental component in the realisation of the IoT vision is represented by Machine-to-Machine communication (M2M). M2M communication refers to the communication between two or more entities that do not necessarily need any direct human intervention (Chen et al., 2012). M2M refers to both wired and wireless technologies to allow communication between devices. Table 3-4 provides a summary of the different definitions/visions of IoT as provided by different researchers.

Table 3-4 IoT Definitions

Definition	Reference (s)
An intelligent infrastructure linking objects, information and people through the computer networks, and where the RFID technology found the basis for its realisation	Ashton (1999)
A new dimension has been added to the world of information and communication technologies (ICTs): from anytime, any-place connectivity for anyone, we will now have connectivity for anything. Connections will multiply and create an entirely new dynamic network of networks – an Internet of Things	International Telecommunications Union (2005)
Links uniquely identifiable things to their virtual representations in the Internet containing or linking to additional information on their identity, status, location or any other business, social or privately relevant information at a financial or non-financial pay-off that exceeds the efforts of information provisioning and offers information access to non-predefined participants	Borgia (2014)
Objects become part of the Internet: where every object is uniquely identified, and accessible to the network, its position and status known, where services and intelligence are added to this expanded Internet, fusing the digital and physical world, ultimately impacting on our professional, personal and social environments	Coetzee and Eksteen (2011)
Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud-computing as the unifying framework.	Gubbi et al. (2013)

From the various definitions identified (Table 3-4) the following definition was derived for the purpose of this study:

The IoT refers to a holistic ecosystem of self-identifiable smart objects with sensing, actuating, computational and communication capabilities which are aware of the physical contexts of their environment and provide tailored services based on this information with minimal human interaction. The IoT enables interaction between the cyber and the physical world in order to enhance human experiences and livelihoods.

3.6.2. Applications of the IoT

Although technology advances enable the possibility of an IoT, it is the application of the IoT which is driving its evolution. The main driving force behind the IoT lies in its potential social, environmental and economic impact on the decisions we make and the actions we take. The application domains that the IoT includes can provide competitive advantage beyond current solutions. Researchers have identified various areas where the IoT has been adopted, such as smart homes, smart businesses, health-care, and security and surveillance. In its inception the IoT was used in the context of supply chain management with RFID tags as the enabling technology (Kortuem et al. 2010). However, in the past decade its application have covered a wide range of industries, including health care, transportation and utilities, to name just a few (Figure 3-9).

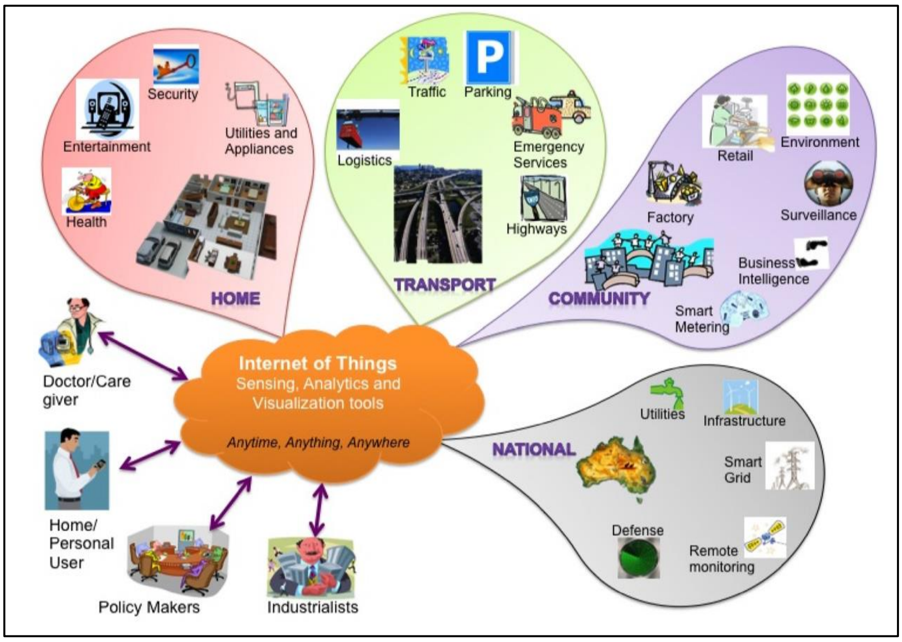

Figure 3-9 Internet of Things Schematic Showing the End Users and Application Areas (Gubbi et al., 2013)

Installing buildings with advanced IoT technologies may help in both reducing the utility resources associated to buildings (that is, electricity and water) as well as in improving the satisfaction of the building occupants, whether workers in office buildings or tenants of private houses. The impact can be viewed in economic terms, that is, the reduction of operational expenditures, as well as in environmental terms, that is, the reduction of the carbon footprint associated with buildings. In this application, a key role is played by sensors, which are used both to monitor resource consumptions, as well as to proactively detect current users' needs (Miorandi et al., 2012). Such a scenario integrates a number of different subsystems, and hence requires a high level of standardisation to ensure interoperability.

Sensors in factories have been used for security, automation and energy usage control for over two decades. The sensors within a factory can be viewed as a subset of the IoT dedicated to factory maintenance. Bi et al. (2014) identified static IT architecture, with its inability to adjust to all types of changes, as a current limitation of enterprise systems within manufacturing organisations. However, the current context of an IoT will offer wireless systems which will provide flexibility to make changes within a factory whenever required as the "things" within the factory will be smart objects/things.

Enterprises are making use of smart meters provided by electric utility companies, in order to reduce costs. By continuously monitoring energy usage within an organisation and using the information gathered to regulate energy usage, utility companies are able to maximise the reduction of costs associated with energy usage. Smart meters form part of a network setup established by utility companies such as electricity providers for monitoring critical utilities and to aid efficient energy resource management. Smart meters are potential IoT applications that are implemented globally (Borgia, 2014).

3.7. Enabling Technologies for the IoT

Technologies at the core of the IoT, such as RFID, have been in existence since the mid-1990s, and one may wonder why the vision of an IoT only started being articulated in 2008. The recent growth of the IoT has been linked to the enabling technologies of the IoT, such as low-cost sensors, low-cost bandwidth, the growth of IPv 6 and the value proposition IoT offers to various industrial sectors (Schofield, 2014). These technologies can be classified as:

- Data collection technologies;
- Big Data and cloud-computing;

- Networking technologies;
- Service Oriented Architecture; and
- Intelligent systems.

3.7.1. Data Collection Technologies

Data collection technologies can be categorised into two categories namely data acquisition and data collection technologies. Data acquisition technologies collect information about the physical environment (temperature and humidity), or about the objects (objectify identify and state). While data collection is accomplished by short range communications, which could be open source standard solutions or proprietary solutions.

Sensing technologies attached to sensors and cameras collect information about the physical environment. Temperature, humidity and brightness are amongst the environmental variables that sensing technologies gather. The cost of sensors has decreased by nearly 50% of the cost value ,from the year 2000 to 2013 and sensory capabilities have increased significantly according to Przydatek, Song, and Perrig (2015). Sensors are now cheap enough and small enough to meet needs of various business cases.

Another essential technology for the development of IoT is Wireless Sensor Networks (WSNs) (Zheng & Jamalipour, 2009). WSNs are a powerful technology for gathering and processing data in a large variety of domains, from environmental to intelligent agriculture. Traditional WSNs consist in a high number of static and resource constrained sensor nodes deployed in an area to sense a certain phenomenon, for example, temperature, and humidity. Sensors are usually powered by small battery, have a limited lifetime and scarce computational and memory capabilities. Sensed data is then transmitted wirelessly via multi-hop communications towards one or a small set of sink nodes, which are more powerful devices where the collected information is elaborated. Predominant standards commonly used in WSN communications include: IEEE 802.15.4, ZigBee (Zheng & Jamalipour, 2009) , Wireless Highway Addressable Remote Transducer Protocol (HART). In the IoT framework, an important role is covered by Low-power wireless personal area networks (LoWPAN) (Buratti, Conti, Dardari, & Verdone, 2009), that is, networks are made up of sensor nodes which exploit the IEEE 802.15.4 standard for energy-efficient wireless communications .

RFID allows to identify objects, people or animals, store information about them and transfer it via wireless communication to other electronic devices. The RFID system consists of two main components: the tag and the reader. The tag is directly applied to an object and identifies it through the Electronic Product Code (EPC), while the reader is the element that collects data from the tag and transmits it to the Internet world. There are two main types of RFID tags: passive and active. The former has no power supplies and can transmit data by using the energy that the reader emits during its passage. Passive tags are very affordable since they are very small, inexpensive and have potentially long life. Their main drawback is that the area in which the tag-reader transmission may take place is very limited ,that is a three meter range (Broll, Keck, Holleis, & Butz, 2009). On the contrary, active tags are equipped with their own power supply for example a battery, thus covering greater distances when communicating and performing more complex operations for instance, they may have sensors installed to monitor the environment (Broll et al., 2009).

An additional way to collect data is through the Near Field Communication (NFC) technology. NFC is a communication technology that enables devices to share information wirelessly by touching them together or bringing them into proximity (Broll et al., 2009). It can be useful for sharing personal data such as contacts/business cards, videos, photos and for making transactions, or providing credentials for access control systems with a simple touch. NFC can be considered as an evolution of RFID as it is built upon RFID systems, but, differently from it, NFC allows bidirectional communications (Borgia, 2014). Specifically, when two NFC devices are located at a distance lesser than four centimeters, a peer-to-peer communication between them is created, and both devices are allowed to send and receive data (Broll et al., 2009). Table 3-5 highlights the usage and application of data collection technologies that could be used in an IoT model.

Table 3-5 Characteristics of Data Collection Technologies

Technology	Use	Application	References
RFID	Identification, storing	Transportation, logistics, tracking animal ID, retail, access control, payment	Ashton, (1999); Buratti et al. (2009)
Sensors and WSN	Sensing, storing, processing, communication	Health/environmental/industrial monitoring, intelligent agriculture, surveillance	Zheng and Jamalipour (2009)
NFC	Communication, identification, storing	Sharing/access information, access control, contactless payment	Broll et al., (2009

3.7.2. Big Data and Cloud-Computing

Big Data refers to voluminous amounts of structured and unstructured data that has the potential to be mined for information (Goldman Sachs, 2014). Big Data analytics is a strategy for gaining richer, deeper insights into customers, partners, and the business and ultimately gaining competitive advantage (Intel, 2013). The availability of Big Data analytics is a key enabler (Intel, 2013). Big Data analytics enables working with data sets whose size and variety is beyond the ability of typical database software to capture, store, manage, and analyse.

For the full realisation of IoT, researchers propose the adoption of cloud-computing (Buyya et al., 2010; Gubbi et al., 2013; Mell & Grance, 2011). The term cloud refers to virtualised resources of computation and storage, which can be dynamically allocated by applications and without human intervention, allowing the digital world to efficiently and flexibility work (Buyya et al., 2010). Cloud-computing can be used for handling the high volume of data. It also provides efficient mechanisms to access virtual storage through cloud database clusters providing supplementary storage capacity in addition to the local storage, which is very limited in most cases. Cloud-computing enables the resource utilisation through the allocating or deallocating storage resources as per demand (Buyya et al., 2010)

3.7.3. Networking Technologies

The new version of IPv6 which is intended to replace IPv4 will enable IoT devices to each have a unique identifier. IPv4 supports 32-bit addresses, which translates to an estimated 4.3 billion addresses, in contrast IPv6 which can support 128-bit addresses, translating into an approximated 3.4 3.4×10^{38} addresses ,which is an almost endless number that can accommodate the 50 billion devices estimated to be connected by the year 2020 (Fleisch, 2010; Schofield, 2014).

The increase in the number of Internet Service Providers and advances in network technologies have resulted in the reduction in the cost of bandwidth (Goldman Sachs, 2014). The cost of bandwidth has declined by a factor of nearly forty over the last ten years resulting in low cost of large data volume transfer over a network (Newe, 2015). With a reduction in the cost of transferring large volumes of data over a network more devices can be connected to the Internet without cost being that much of a barrier.

3.7.4. Service Oriented Architecture (SOA)

Service Oriented Architecture (SOA) addresses some of the challenges of IoT such as abstraction of objects, networks and services whilst also offering a loose coupling of components (Borgia, 2014; Lubbers & Greco, 2010). SOA is crucial for hiding the heterogeneity of hardware, software, data formats, technologies and communication protocols characterising IoT (Huang, 2013). SOA standards were originally designed for connecting programs running on static computers, their direct application to IoT devices is not feasible but requires an adaptation to this context. Basically, the SOA approach relies on three layers, each responsible for different functionalities (Borgia, 2014). The first layer is responsible for objects abstraction, that is., each object or single functionality implemented by the object is abstracted and represented as service. In addition, it offers semantics and procedures to access objects. The second layer is responsible for the management of objects and services, providing a way to automatically and dynamically discover them, monitor them, and make public their status. Additional responsibilities are to remotely manage services, and to maintain a correspondence between objects and the available services on them. Finally, the third layer provides all the mechanisms for management of the service and objects composition. And manages how to dynamically create new services from a single or set of basic services in real-time. The REST technologies and architecture have become widely used implementations of SOA (Lubbers & Greco, 2010). REST stands for Representational State Transfer, which is an architectural style for networked hypermedia applications, it is primarily used to build Web services that are maintainable and scalable (Huang 2013). A service based on REST is called a RESTful service.

3.7.5. Intelligent Systems

Intelligent systems are algorithmic models used to solve complex problems through the modelling of biological or natural intelligence. (Engelbrecht, 2007). Computational intelligence (CI) mechanisms are used to implement intelligent systems. CI is a sub-branch of AI and is the study of adaptive mechanisms to facilitate intelligent behaviour in complex and changing environments. According to Engelbrecht (2007) the mechanisms include AI paradigms with the ability to learn adapt to new situations, to generate, abstract, discover and associate. The current trend is to use a hybrid of the individual CI paradigms to solve real-world problems since no one paradigm is superior to the other in all situations. By doing this one capitalises on the respective strengths of the components of the hybrid CI system and eliminates the weaknesses of individual paradigms. Novel fusion CI algorithms need to be developed to make sense of the data collected. State-of-the-art non-linear, temporal machine learning methods based on CI mechanisms and other AI techniques are necessary to achieve automated decision making. Examples of these intelligent algorithms include artificial neural networks, evolutionary computing and swam intelligence. Coupled with logic, deductive reasoning, expert systems and machine learning systems intelligent algorithms, such as decision trees, form the field of AI.

Neural networks are non-linear statistical data modelling tools that are inspired by the functionality of the human brain using a set of interconnected nodes (Silverstong and Sheetz, 2004, cited in Chintalapati and Jyotsna, 2013). The learning algorithm used by a neural network can be either supervised or unsupervised. Once a neural network has received the necessary training, it forms a classifier.

A decision tree is a tree structure consisting of nodes that each represent a test of an attribute with each branch representing a result of the test (Kirkos, Spathis, & Manolopoulos, 2007). The tree splits observations into mutually exclusive subgroups until observations can no longer be split. A popular splitting algorithm used is the ID4.5 algorithm. The ID4.5 algorithm builds a decision tree by employing a top-down, greedy search through the given sets of training data to test each attribute at every node (Bahety, 2012.). The algorithm uses a property called Information Gain to select which attribute to test at each node –this determines how well a given attribute separates the training examples based on their target classification. Decision trees require little effort for data preparation unlike some statistical techniques and they are easy to interpret (Deshpande, 2011). While decision trees can be useful, they are associated with some disadvantages. It is observed that only successful paths are considered for trees and that not much thought is given to the probability of each branch within a tree (eNotes, 2011).

There are many differences between these decision trees and neural networks, but in practical terms, there are three criteria that should be considered when doing a comparison: speed, interpretability, and accuracy (Deshpande, 2011).

Decision Trees

- Are faster once trained, although both algorithms can train slowly depending on exact algorithm and the dimensionality of the data. This is because a decision tree inherently "throws away" the input features that it doesn't find useful, whereas a neural network will use them all unless the feature selection is a pre-processing step.

- If it is important to understand what the model is doing, decision trees are more interpretable.
- Decision trees only model functions which are axis-parallel splits of the data.
- Decision trees can be pruned to avoid over-fitting.

Neural Networks

- Are slower both for training and classification, and less interpretable.
- If data arrives in a stream, incremental updates with stochastic gradient descent can be performed, unlike decision trees, which use inherently batch-learning algorithms.
- Can model more arbitrary functions such as non-linear interactions and therefore might be more accurate, provided there is enough training data and can be pruned to avoid over-fitting as well.

3.7.6. Summary of Enabling Technologies and Techniques

Several technologies enabling the growth of IoT have been discussed in this section (Section 3.7). The reduction in the cost of sensing technologies and their increased sensory capabilities entails an increase in the number of devices and objects that can collect information about the environment. Furthermore, an increase in the sensory capabilities provided by the data acquisition technologies will provide more detailed and in-depth information about the physical environment. Coupled with advances in the field of data collection technologies, such as WSN, RFID and NFC, and their transmission protocols, such as ZigBee and HART, data pertaining to a particular context can be gathered over a large geographical location. For example, the use of WSN in agriculture to collect data relating to the acidity of the soil over three thousands hectors of land (Envirothon, Issue, Objectives, Agriculture, & Grown, 2014).

Big Data analytics promises to process the data collected from the vast number of devices that will be connected to the Internet. The use of cloud-computing will allow users to utilise computational resources that can handle Big Data analytics. The combination of Big Data analytics and cloud-computing will enable users to not only gather vast amount of data but also enable them to process it without having to acquire high infrastructural costs (Section 3.7.2). AI mechanisms can be used for the efficient processing of an IoT collected data within a Big Data analytics application (Section 3.7.5). Furthermore, the introduction of IPv6 will allow each device that connects to the Internet to have its own unique IP addresses that will allow users and other applications on the Internet to directly interact with it (Section 3.7.3). Table 3-6 illustrates the enabling technologies of IoT and their respective use as discussed in the previous sections.

Table 3-6 Enabling Technologies of IoT

Technology	Techniques	Use	References
Sensors, cameras		Data acquisition	Broll et al. (2009)
WSN, RFID, NFC		Data collection	Broll et al. (2009)
IPv6 (Networking technology)		Addressing of devices/objects on the Internet	Fleisch (2010); Schofield (2014)
Big Data analytics		Processing of voluminous data	Goldman Sachs (2014); Intel (2013)
Cloud-computing		Storage and processing of data	Buyya et al. (2010)
SOA	REST architecture and technologies	Abstraction of devices, networks, and services	Borgia 2014; Lubbers and Greco 2010
AI and CI	Decision trees Neural networks	Processing of data; Automation of processes	Engelbrecht, 2007; Silverstong and Sheetz, 2004

The aforementioned enabling technologies for IoT have led to the accelerated growth of IoT over the last five years. However, the growth of IoT and its adoption have encountered some challenges. The challenges shall be discussed in the next section.

3.8. Challenges Faced by the IoT

The envisioned adoption of the IoT will have to overcome a range of challenges, which fall under four categories, namely:

- Security;
- Big Data management; and
- Network architecture and protocol standardisation.

3.8.1. Security

Security is always a concern when personal information is deployed on a network on a large scale (Coetzee & Eksteen, 2011; Fleisch, 2010). The individuals' right to privacy needs to be protected. It is important for individuals and societies to trust in an IoT ecosystem that ensures their information is not be made available to third parties and does not have a negative impact on their lives (Miorandi et al., 2012). The concerns of data and information security applies to:

- Data Confidentiality;

- Privacy and
- Trust.

Data Confidentiality

Data confidentiality refers to the access and manipulation of data and information by individuals or entities with authorised authority (Desai, 2016). The authorisation encompasses both users and objects. Standardised access control mechanisms will have to be redefined due to the vastness of the data generated by multiple objects within an IoT ecosystem in order to address concerns related to data confidentiality. Data access needs to be managed in both an online and offline flexible manner, that is, the changing of access rights at run-time and as well as application of the access rights to dynamic data streams. Identity management solutions have to be enforced in order to successfully manage the identification of objects and the related authorisation processes in order to implement access control mechanisms. However, objects identification raises novel challenges not addressed by research conducted on user identification. As objects may be accessed by various services for various purposes, for instance in horizontally aligned applications such as smart city electrification, objects may be identified as per service provider's use. In such a situation it is essential that information transmitted by the object conforms to the access rights the specific service provider has and therefore the identity needs to be related to the access control implemented depending on the service provider's authorisation.

Privacy

The term privacy relates to the rules under which an individual or entity can access data. Health care facilities face the greatest challenge in this aspect (Desai, 2016). The envisioned increase in the use of wireless technologies in an IoT environment poses security challenges as wireless mediums of data exchange are particularly vulnerable to potential eavesdropping and masked attacks. If the information is accessed outside the bounds of stipulated policies, the privacy of individuals' information is compromised as it is made available to unauthorised individuals or entities. Privacy policies with explicit conditions for the identification and localisation of smart objects need to the established in order for the anonymity of objects to be implemented so as to reduce potential breaches of privacy.

Trust

Trust refers to the security policies regulating the access to resources and credentials required to satisfy a service's provision. Trust negotiation processes, in which one party provides the necessary credentials to gain access to a service or resources from another party, need to be standardised. This can be achieved through peer-to-peer negotiation.

3.8.2. Big Data Management

With data being provided by multiple sensors and at high frequencies, the issue of Big Data management arises. Big data requires clusters of servers to support the tools that process large volumes, high velocity, and varied formats of Big Data (Intel 2013). Finding scalable solutions to efficiently store and interpret the masses of data remains a major technological challenge (Chui et al. 2010). Managing Big Data is challenging due to the different data properties. IoT data is generated by a variety of objects and sensors, each with different methods for data representation and semantics. Moreover, the large number of IoT devices generate huge volumes of data to be collected - petabytes and more (Borgia 2014). The collected data often includes a time–space relationship, that is, information about position and time. The time-space relationship describes the dynamics of the objects' location and so-called pervasive location information (Chintalapati and Jyotsna, 2013). In contrast with today's applications, where data is usually used by single applications, data will be shared among different IoT applications, thus requiring a greater interoperability. This requires data multi-dimensionality, which refers to the integration of different types of sensor data to monitor simultaneously a number of indicators, such as temperature, pressure and light.

IoT data properties generate new data management issues that change the way the system works. Indeed, IoT data management moves from being a classic ''offline'' system, where storage/query processing/transaction operations are managed offline, to create an ''online/offline'' system, where processing and analysis happen in real time. The scalability of data is important, and efficient indexing methods need to be developed in order to find specific data items easily. Suitable representation schemes are also needed to capture the heterogeneity of objects and metadata, and to enable their self- description. In addition, interoperability among different data is also important. Approaches introducing an abstraction level may solve them (Borgia 2014).

Borgia (2014) identifies data archiving as another challenge of big data management, which raises a number of correlated challenges. Firstly, as time passes and data may become obsolete, suitable policies to retain or delete data are required. Inadequate policies may lead to a loss of data, inaccurate recording, or missing information. Solutions relying on the semantic continuity of data elements, by using timestamps, can be adapted to solve the aforementioned issues. Secondly, suitable models for storing Big Data are also challenging. Several models have been proposed, but they are tailored for specific technologies. For example, the RFID-Cuboids model manages efficiently massive RFID data, achieving a significant data compression and speeding up the analysis process. Finally, understanding the optimal location for storing data is also challenging. IoT data storage can be local, distributed or centralised.

3.8.3. Network Architecture and Protocol Standardisation

Finding a scalable, flexible, secure and cost-efficient architecture, able to cope with the complex IoT scenario, is one of the main challenges for fast the IoT adoption. A number of different architectural solutions have been proposed in the past years (Borgia, 2014). In addition, some proposals are tailored for specific applications such as healthcare, meter reading, enterprise services, while others are designed for specific technologies (Gubbi et al., 2013). However, an excessive wide range of different technical architecture solutions makes interoperability difficult, slowing down the IoT development process (Nataliia & Elena, 2015). Therefore, developing an IoT reference architecture is an objective that recently has found support within the IoT community. The major standards bodies such as Institute of Electrical and Electronics Engineers (IEEE), ITU and ETSI started working on its realisation, and their efforts resulted in the design of two network architecture for an IoT:

- A hierarchical network architecture for scalable connectivity, and
- A hierarchical network architecture for high capacity.

Both solutions are based on a hierarchical organisation of the network that allows it to satisfy the IoT requirements. In the first case, the emphasis is on network scalability, ensuring a reliable and efficient connection between the multitudes of devices. In the second case, the emphasis is on the efficient management of the high traffic load to which the network is expected to be subjected (Borgia, 2014; Gubbi et al., 2013). Table 3-6 shows the challenges faced by the IoT identified in this section.

Table 3-7 Challenges faced by the IoT

IoT challenge	References
Security (data confidentiality; privacy; and trust).	Desai (2016); Fleisch (2010)
Big Data management	Borgia (2014); Chintalapati and Jyotsna (2013)
Network architecture and protocol standardisation	Gubbi et al. (2013); Nataliia and Elena (2015)

3.9. Architectures and Model of an IoT

In order to cement the understanding of an IoT environment the techniques used and its technologies it is important to have a holistic view of the architectures and how the various elements within it interact. At the core of each IoT ecosystem are three main components the sensing object, a data transportation/network medium and a data processing and consumption platform (Borgia, 2014; Coetzee & Eksteen, 2011; Miorandi et al., 2012). As noted by multiple researchers one of the main challenges the vision of IoT faces is the lack of unifying standard architecture, to facilitate the implementation of an IoT ecosystem (Miorandi et al., 2012; Schofield, 2014). In the next section a review of various architectures as presented by selected researchers shall be undertaken. These architectures are conceptualised and classified as follows:

- The Three Phase Data flow;
- The Four Layered Architecture; and
- The Seven Level Reference Model.

3.9.1. The Three Phase Data Flow within an IoT

Borgia (2014) describes the structure of an IoT ecosystem by means of the interaction between the cyber-physical systems (CPS) through the flow of data. A CPS is an information systems that is integrated with physical processes (Section 3.5.2). CPS's control and manage variables within the physical systems in order to make them more efficient (Chen et al., 2012; E. A. Lee, 2008; Rajkumar, Lee, Sha, & Stankovic, 2010). The interaction of the various components within an IoT environment occur in three phases specifically the collection phase, transmission phase and process phase (Figure 3-10).

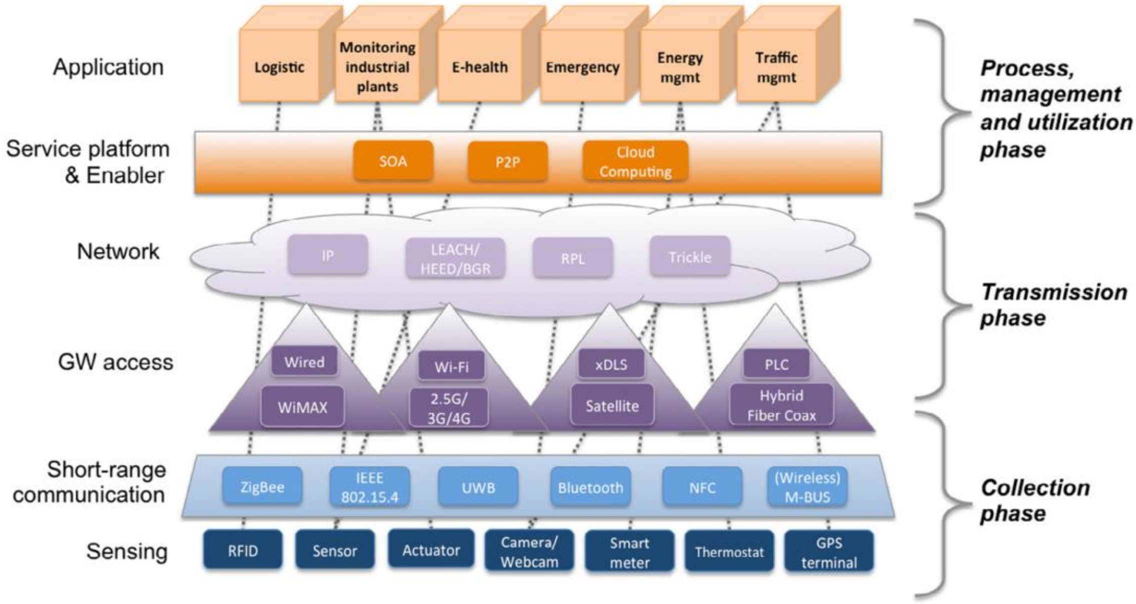

Figure 3-10 IoT Data Flow Architecture of an IoT (Borgia, 2014)

Collection Phase

The collection phase refers to the collection of data from the physical environment in real-time through sensory and identification technologies (Borgia, 2014). The collection phase consists of two layers namely the short-range communication and the sensing layers. RFIDs and sensors provide identification of physical objects and environmental context parameters such as temperature. The collection phase lays the foundation of an IoT ecosystem through the gathering of data about the environment or by providing identification for objects within it. Each device is individually addressable so that it can be accessed and transmit data incompliance with Internet standards. RFIDs provide an object a unique identity and also store information about it, which is transferable wirelessly to other electronic devices. RFID systems consist of a tag and a reader. The tag is placed on the object giving it identity and storing information about the object. The reader is a device that collects information from the tag and transfer it to other devices wirelessly. Sensors measure or detect environmental variables such as temperature, light, humidity and location then converts them into a form, for instance digital in this case, that is human readable or can be used for other purposes. Sensors therefore bridge the physical and cyber worlds. Sensors are connected to nodes which are the interface between the sensor and the physical world. A node can be connected to one or sometimes several sensors. The sensors can be interconnected and form a network which transfers the data collected to a central location. WSNs can be used to monitor environmental conditions and transfer the data collected to a data storage and processing location. The WSN will monitor conditions of the space they reside in or the encompassing of things.

Transmission Phase

Once data is collected through the sensing technologies, it is transmitted across a network, so that is can be consumed by other applications. The transmission phase includes mechanisms of data collection and deliver to applications and external servers. Techniques therefore need to be established for accessing the network through gateways and heterogeneous technologies to transfer data to the desired destination. The network is accessed by heterogeneous communication technologies such as Ethernet, Wireless Local Area Networks (WLAN), Wi-Fi, Wi-Max just to name a few. Wireless technologies have been viewed as the main technology drivers for IoT from a network communication perspective due to their low cost of deployment and their flexibility. The data is transferred over a network through different protocols such as TCP/IP, web-sockets and Bluetooth.

Process, Management and Utilisation Phase

SOA concepts are applied within IoT in order to carry out the critical functions. Cloud services are at the heart of the SOA concepts in the full realisation of IoT. (Buyya et al., 2010). With an estimated 50 billion devices to be online by the year 2020 one the outcomes of IoT is the creation of large volumes of data (Gubbi et al., 2013). The storage, ownership and expiry of the data become critical issues. The data has to be stored and utilised efficiently for smart monitoring and actuation. In this phase functions such as data filtering and aggregation, semantic analysis and information utilisation are performed. These functions can be performed by intelligent systems.

3.9.2. Four Layered Architecture

Various researchers have used a segmented architecture to describe the interaction of objects within an IoT environment (Bi et al., 2014; Bucherer & Uckelmann, 2011; Green, 2014; Yu & Wang, 2012). Yu and Wang (2012) made use of a Four Layered Architecture of IoT which consisted of a sense knowledge layer (objects-things layer), network structure layer, management service/SOA layer and integrated application layer to describe objects and there interaction in an IoT. In an IoT system, data is generated by multiple kinds of devices, processed in different ways, transmitted to different locations, and acted upon by applications.

Figure 3-11 depicts a conceptual architecture of an IoT with four layers as identified by researchers (L. Da Xu, He, & Li, 2014; Yu & Wang, 2012). The model describes the layers within an IoT ecosystem (Yu & Wang, 2012). The layers are the sensing/objects-things layer, the Network Layer, services layer and the Applications Layer.

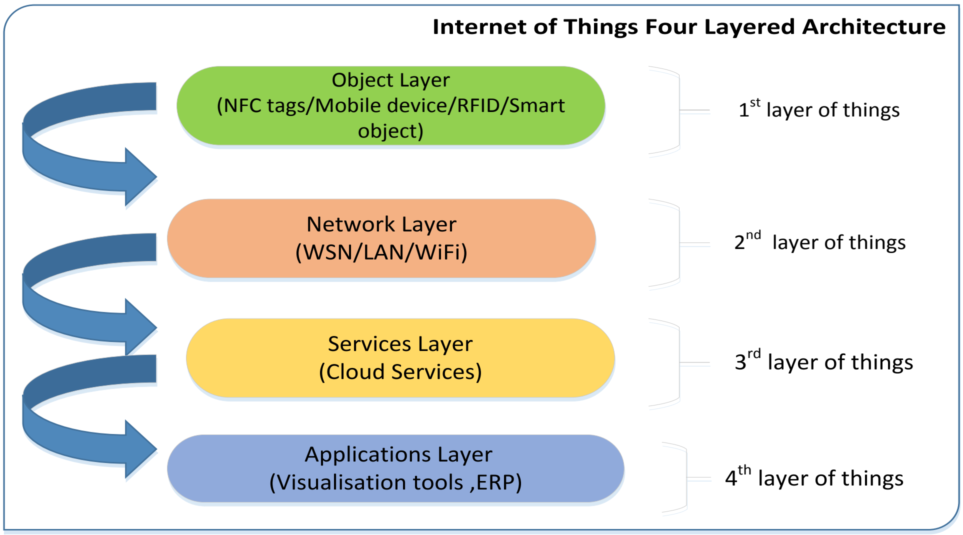

Figure 3-11 Four Layered IoT Architecture-Adapted from L. Da Xu, He, and Li (2014); Yu and Wang(2012).

Sensing/Object Layer

The first layer consists of smart objects or "things" within an IoT (Gubbi et al., 2013; Kortuem et al., 2010; Miorandi et al., 2012; Nataliia & Elena, 2015). Some of them will be wearable, but the majority will be in the infrastructure. In this vision, humans will be completely immersed in the world of technology, leading to the so-called Immersed human (Gubbi et al., 2013). The ability of smart objects to be identifiable, to communicate and to interact with other smart objects or end users lays the foundation for enabling the vision of IoT to become a reality (Miorandi et al., 2012). Therefore a "thing" or smart object within an IoT ecosystem can be defined as a physical embodiment that possesses:

- An identifier, that is identifiable (Miorandi et al. 2012; Coetzee & Eksteen 2011);
- Sensory and control capabilities (Miorandi et al. 2012); and
- Communication functionality and has some basic computing capabilities that enable interaction (Nataliia & Elena 2015).

Da Xu et al. (2014) referred to the first layer as the sensing layer, this is the equivalent layer to the Objects Layer. In the sensing layer, the wireless smart systems with tags or sensors are now able to automatically sense and exchange information among different devices. These technology advances significantly improve the capability of IoT to sense and identify things or environment.

Network Layer

The second layer of an IoT is the Network Layer (Bi et al., 2014; Borgia, 2014). The Network Layer contains network technologies and protocols for the transfer of data from the sensing/Objects Layer to the sensing layer. The components include Local Area Networks (LAN), WSN and Wi-Fi technologies. Another role of networking layer is to connect all things together and allow things to share the information with other connected things(L. Da Xu et al., 2014). WSN enable the collection, processing, analysis and distribution of information collected from various smart objects within an IoT (Borgia, 2014). Bi et al. (2014) argue that WSNs are the most important infrastructure of IoT. Through WSN middleware network infrastructure is connected to a SOA and sensor networks to provide access to various smart-objects in a deployment independent manner (Gubbi et al., 2013).

Services Layer

The services layer relies on the middleware technology that provides functionalities to seamlessly integrate services and applications in IoT (L. Da Xu et al., 2014). The middleware technology provides the IoT with a cost-efficient platform, where the hardware and software platforms can be reused. A main activity in the service layer involves the service specifications for middleware, which are being developed by various organisations. Cloud-computing is a key component of the services layer. Cloud-computing provides the abstraction of a set of computers and offer computation and storage services. Cloud-computing also provides a platform for SOA within IoT. Cloud-computing enables ubiquitous on-demand computing services through network access. For example networks, servers, storage applications, and services that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell & Grance, 2011).

Applications Layer

The visualisation of objects is critical for an IoT application as it enables interaction of end users with smart-objects within the environment (Gubbi et al., 2013). This visualisation forms part of the integrated application layer which is the fourth layer within the Four Layered Architecture. For example, a visualisation tool can be used get locations and the status of equipment from remote locations with minimal human interaction to initiate the process. The fourth layer is also referred to as the Applications Layer where enterprises make use of various enterprise applications, such as ERP systems, to enhance operational efficiency (Fleisch, 2010; Yu & Wang, 2012). ERP systems are software packages that integrate an organisation's business processes and all information that is relevant to manage the organisation (Turban, Volonino, McLean & Wetherbe, 2010). This integration streamlines information flow and results in benefits in value chain optimisation such as reduced inventory costs, process improvements and improved customer service (Beheshti, 2006).

3.9.3. IoT Seven Level Reference Model

Green (2014) proposed a reference model, consisting of the following seven levels:

1. Physical Devices and Controllers;
2. Connectivity;
3. Edge (Fog Computing);
4. Data Accumulation;
5. Data Abstraction;
6. Application; and
7. Collaboration and Processes.

The purpose of the Seven Level Reference Model is to provide clear definitions and descriptions that can be applied accurately to elements and functions of IoT systems and applications reference (Green, 2014). The model also defines each level with terminology that can be standardised to create a globally accepted frame of reference (Green, 2014). It also does not restrict the scope or locality of its components. For instance, from a physical perspective, every element could reside in a single rack of equipment or it could be distributed across the world. Additionally, according to Green (2014) the model enables data processing occurring at each level to range from trivial to complex, depending on the situation. The model describes how tasks at each level should be handled to maintain simplicity, allow high scalability, and ensure supportability. Finally, the model defines the functions required for an IoT system to be complete. Figure 3-12 illustrates the IoT Seven Level Reference Model proposed by Green (2014) and its levels. It is important to note that in the IoT, data flows in both directions. In a control pattern, control information flows from the top of the model (Level 7) to the bottom (Level 1). In a monitoring pattern, the flow of information is the reverse. In most systems, the flow will be bidirectional.

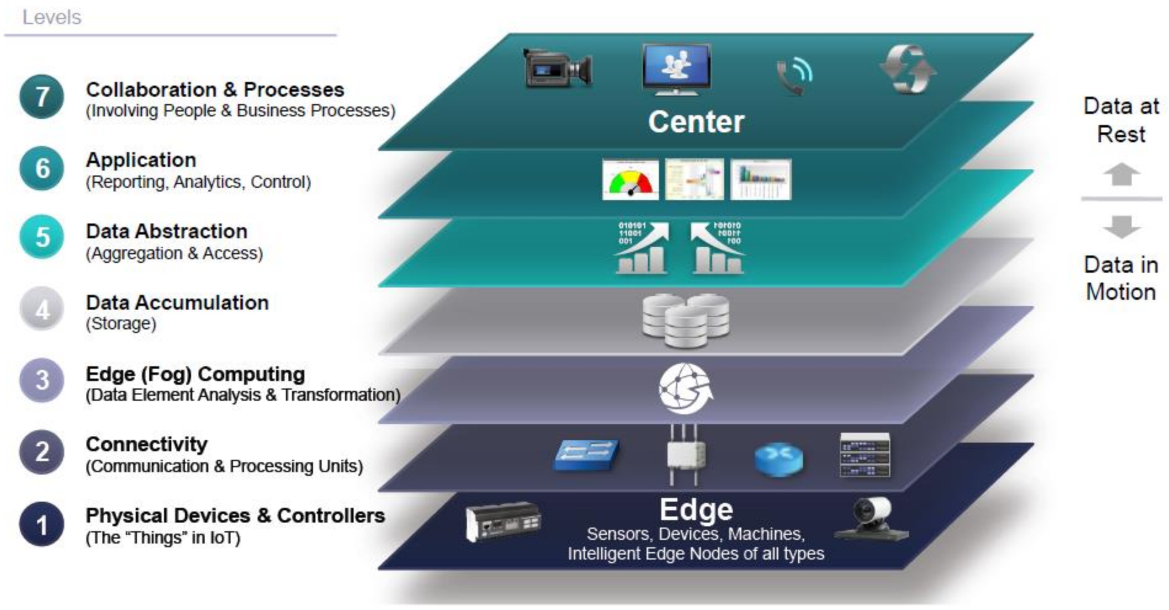

Figure 3-12 IoT Seven Level Reference Model (Green, 2014)

Level 1: Physical Devices and Controllers

Green's Seven Level Reference Model starts with Level 1 which contains the "The Things" in an IoT ecosystem. These are the "things" in the IoT, and they include a wide range of endpoint devices that send and receive information. Devices are diverse, they are different in size, context of use and manufacturer. Some devices are the size of a silicon chip (Kortuem et al., 2010), whilst some are as large as vehicles. The IoT supports the entire range. Dozens or hundreds of equipment manufacturers produce the diverse IoT devices.

Level 2: Connectivity

According to Green (2014), communications and connectivity are concentrated in Level 2. The most important function of Level 2 is reliable, timely information transmission, which includes transmissions:

- Between smart objects (Level 1) and the network;
- Across networks (horizontal transmission) within level 2; and
- Between the network (Level 2) and low-level information processing occurring at Level 3.

Traditional data communication networks have multiple functions, as evidenced by the International Organisation for Standardisation's (ISO) Open Systems Interconnection (OSI) 7-layer reference model. However, a complete IoT system contains many levels in addition to the communications network. One objective of the Seven Level Reference model is for communications and processing to be executed by existing networks. The model does not require or indicate creation of a different network, it relies on existing networks. However, some legacy devices are not IP-enabled, which will require introducing communication gateways. Other devices will require proprietary controllers to serve the communication function. As Level 1 devices increase, the ways in which they interact with Level 2 connectivity equipment may change. Regardless of the details, Level 1 devices communicate through the IoT system by interacting with Level 2 connectivity equipment.

Level 3: Edge (Fog) Computing

The functions of Level 3 are driven by the need to convert network data flows into information that is suitable for storage and higher level processing at Level 4 (data accumulation). This means that Level 3 activities focus on high-volume data analysis and transformation. For example, a Level 1 sensor device might generate data samples multiple times per second, 24 hours a day, 365 days a year. A basic tenet of the IoT Seven Level Reference Model is that the most intelligent system initiates information processing as early and as close to the edge of the network as possible. This is sometimes referred to as fog computing. Level 3 is where this occurs. Given that data is usually submitted to the connectivity level (Level 2) networking equipment by devices in small units, Level 3 processing is performed on a packet-by-packet basis. This processing is limited, because there is only awareness of data units—not "sessions" or "transactions." Level 3 processing can encompass many examples, such as:

- Evaluation: Evaluating data for criteria as to whether it should be processed at a higher level;
- Formatting: Reformatting data for consistent higher-level processing;
- Expanding/decoding: Handling cryptic data with additional context (such as the origin);
- Distillation/reduction: Reducing and/or summarising data to minimise the impact of data and traffic on the network and higher-level processing systems; and
- Assessment: Determining whether data represents a threshold or alert; this could include redirecting data to additional destinations Networking systems are built to reliably move data, the data is "in motion."

Level 4: Data Accumulation

Prior to Level 4, data is moving through the network at the rate and organisation determined by the devices generating the data. The model is event driven. As defined earlier, Level 1 devices do not include computing capabilities themselves. However, some computational activities could occur at Level 2, such as protocol translation or application of network security policy. Additional compute tasks can be performed at Level 3, such as packet inspection. Driving computational tasks as close to the edge of the IoT as possible, with heterogeneous systems distributed across multiple management domains represents an example of fog computing. Fog computing and fog services will be a distinguishing characteristic of the IoT. Most applications cannot, or do not need to, process data at network wire speed. Applications typically assume that data is "at rest"—or unchanging—in memory or on disk. At Level 4, Data Accumulation, data in motion is converted to data at rest. Level 4 determines:

- If data is of interest to higher levels: If so, Level 4 processing is the first level that is configured to serve the specific needs of a higher level.
- If data must be persisted: Should data be kept on disk in a non-volatile state or accumulated in memory for short-term use?
- The type of storage needed: Does persistency require a file system, big data system, or relational database?
- If data is organised properly: Is the data appropriately organized for the required storage system?
- If data must be recombined or recomputed: Data might be combined, recomputed, or aggregated with previously stored information, some of which may have come from non-IoT sources.

As Level 4 captures data and puts it at rest, it is now usable by applications on a non-real-time basis. Applications access the data when necessary. In short, Level 4 converts event-based data to query-based processing. This is a crucial step in bridging the differences between the real-time networking world and the non-real-time application world.

Level 5: Data Abstraction

IoT systems will need to scale to a corporate or global level and will require multiple storage systems to accommodate IoT device data and data from traditional enterprise ERP, HRMS, CRM, and other systems. The data abstraction functions of Level 5 are focused on rendering data and its storage in ways that enable developing simpler, performance-enhanced applications. With multiple devices generating data, there are many reasons why this data may not land in the same data storage:

- There might be too much data to put in one place;
- Moving data into a database might consume too much processing power, so that retrieving it must be separated from the data generation process. This is done today with online transaction processing (OLTP) databases and data warehouses;
- Devices might be geographically separated, and processing is optimised locally; and
- Levels 3 and 4 might separate “continuous streams of raw data” from “data that represents an event.” Data storage for streaming data may be a big data system, such as Hadoop. Storage for event data may be a relational database management system (RDBMS) with faster query times.
- Different kinds of data processing might be required. For example, in-store processing will focus on different things than across-all-stores summary processing.

For these reasons, the data abstraction level must process many different things. These include:

- Reconciling multiple data formats from different sources;
- Assuring consistent semantics of data across sources;
- Confirming that data is complete to the higher-level application;
- Consolidating data into one place using extraction, transformation and loading database functions or providing access to multiple data stores through data virtualisation;
- Protecting data with appropriate authentication and authorisation;
- Normalising or denormalising and indexing data to provide fast application access.

Level 6: Application

Level 6 is the application level, where information interpretation occurs. Software at this level interacts with Level 5 and data at rest, so it does not have to operate at network speeds. The IoT Reference Model does not strictly define an application. Applications vary based on vertical markets, the nature of device data, and business needs. For example, some applications focus on monitoring device data, while others focus on controlling devices; some combine device and non-device data. Monitoring and control applications represent many different application models, programming patterns and software stacks, leading to discussions of operating systems, mobility, application servers, hypervisors, multi-threading and multi-tenancy. It is worth noting that the complexity of the applications varies widely. For example, mission-critical business applications such as ERP are very different from specialised industry solutions to mobile applications that handle simple interactions. Additional examples are an analytic application that interprets data for business decisions system management, or control centre applications that control the IoT system itself and do not act on the data produced by it.

Level 7: Collaboration and Processes

One of the main distinctions between Green's Seven Level Reference Model and Yu and Wang (2012) is that Green's model lays emphasis on people and processes. This difference becomes particularly clear at Level 7: Collaboration and Processes. The IoT system, and the information it creates, is of little value unless it yields action, which often requires people and processes. Applications execute business logic to empower people. People use applications and associated data for their specific needs. Often, multiple people use the same application for a range of different purposes. The objective is not the application—it is to empower people to do their work better. Applications (Level 6) give business people the right data, at the right time, so they can do the right thing. But frequently, the action needed requires more than one person. People must be able to communicate and collaborate, sometimes using the traditional Internet, to make the IoT useful. Communication and collaboration often requires multiple steps. And it usually transcends multiple applications.

In order to address the security issues of IoT raised by several researchers (Desai, 2016; Newe, 2015) , Green (2014) proposes the following security measures :

- Secure each device or system;
- Provide security for all processes at each level, such as identity management, authentication and authorisation, secure and network protocols; and
- Secure movement and communication between each level, whether north- or south-bound.

3.9.4. Summary of an IoT Structure and Components

The structure and components of an IoT have been presented by different schools of thought by researchers (Borgia, 2014; L. Da Xu et al., 2014; Green, 2014). All three views (architectures/model) discussed in this section identify the various components within an IoT and there are several similarities. For example, within each view presented are segmented areas which discuss the components within them. However, the focus on each of the views is different to the others. With Borgia (2014) the emphasis is on the flow of data within the IoT within three phases. The interaction of the various components and procedures performed on the data are reviewed through the data flow process. The layered architecture on the other hand identifies the components that are within each layer with little or no emphasis on how they interact with each other. The layered architecture describes the roles played by the components within each layer. Green's Reference model (2016) aims at defining and describing the elements and function within each of the seven level of IoT that can be standardised to create a globally accepted frame of reference.

The different views of IoT can be used together to create a more comprehensive architecture of IoT as a way of providing a standardised structure of building IoT systems. Figure 3-16 illustrates the combination of the different key features of each view to propose a comprehensive IoT model. The architecture can inherit key elements from all three views such as the data flow (Section 3.9.1), the architecture (3.9.2) and functions (Section 3.9.3).

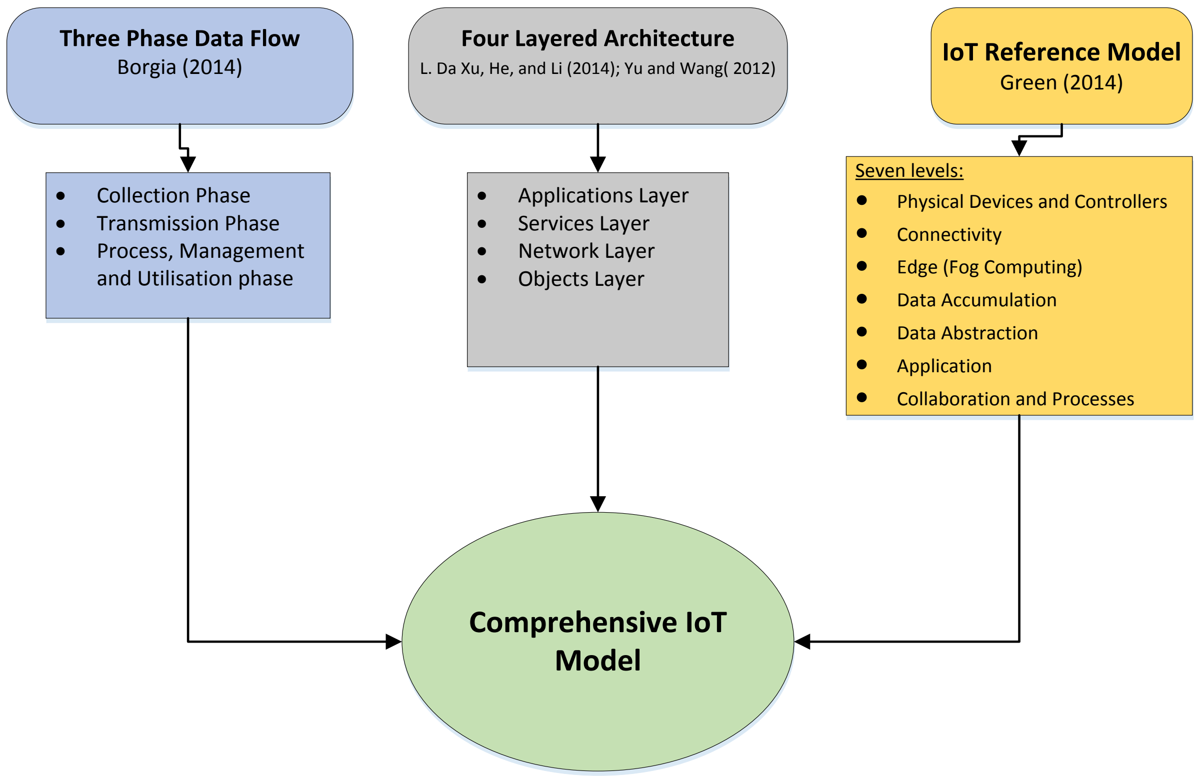

Figure 3-13 Proposed IoT Model

The impact of standardisation within IoT led to the successful development and implementation of a multiple vendor project within the manufacturing sector also referred to as the Smart Factory. The development and implementation of the Smart Factory as part of the fourth industrial revolution shall be discussed in the following section.

3.10. The Fourth Industrial Revolution

In today's competitive business environment, companies are faced with challenges of an ever-changing global market which requires rapid decision-making for improved productivity. Manufacturing companies are continuously seeking ways to improve productivity whilst also reducing manufacturing costs. The manufacturing industry has been a pioneer in the provision of innovative technologies to improve productivity and at the heart of the first three industrial revolutions.

The First Industrial Revolution led to the introduction of water- and steam-powered mechanical manufacturing facilities inspired by James Watts' vapour-powered technology. At the start of the 20th century the Second Industrial Revolution, which was based on electrification to enable mass production and the division of labour occurred. This was followed by the Third Industrial evolution, which was a result of the rise of information technology. The ability to network resources, information, objects and people has led to the creation of the Internet and the services industry. This phenomenon, according to Kagermann, Wahlster and Helbig, 2013 has led to the Fourth Industrial Revolution. The Fourth Industrial Revolution has been referred to as Industry 4.0. Industry 4.0 has come about as a result of the emergence of the IoT and CPS systems in the manufacturing industry (Kagermann et al. 2013). The term was coined by a group of researchers in a report aimed at increasing the competitiveness of Germany's manufacturing industry. Figure 3-14 summarises the four industrial revolutions as presented by Kagermann et al. (2013).

Industry 4.0 aims at addressing the challenges of shorter product lifecycles, and high customisation of products and stiff global competition (Weyer, Schmitt, Ohmer, & Gorecky, 2015). It further promises efficient manufacturing and energy waste production through the smart manufacturing. Smart manufacturing can be explained by means of an illustration as provided by Oberhaus (2015).

"*If your phone knows that it is going to "die" in the near future, it can notify the factory, which can alter its production levels to reflect the data coming in from the smart objects produced there. When your phone dies, there will already be another one waiting for you, meaning the days of back-ordering are numbered. What's more, as this process becomes more sophisticated and integrated, your phone will arrive already programmed with your custom settings, just like how you had it when it gave out on you a few hours ago*."

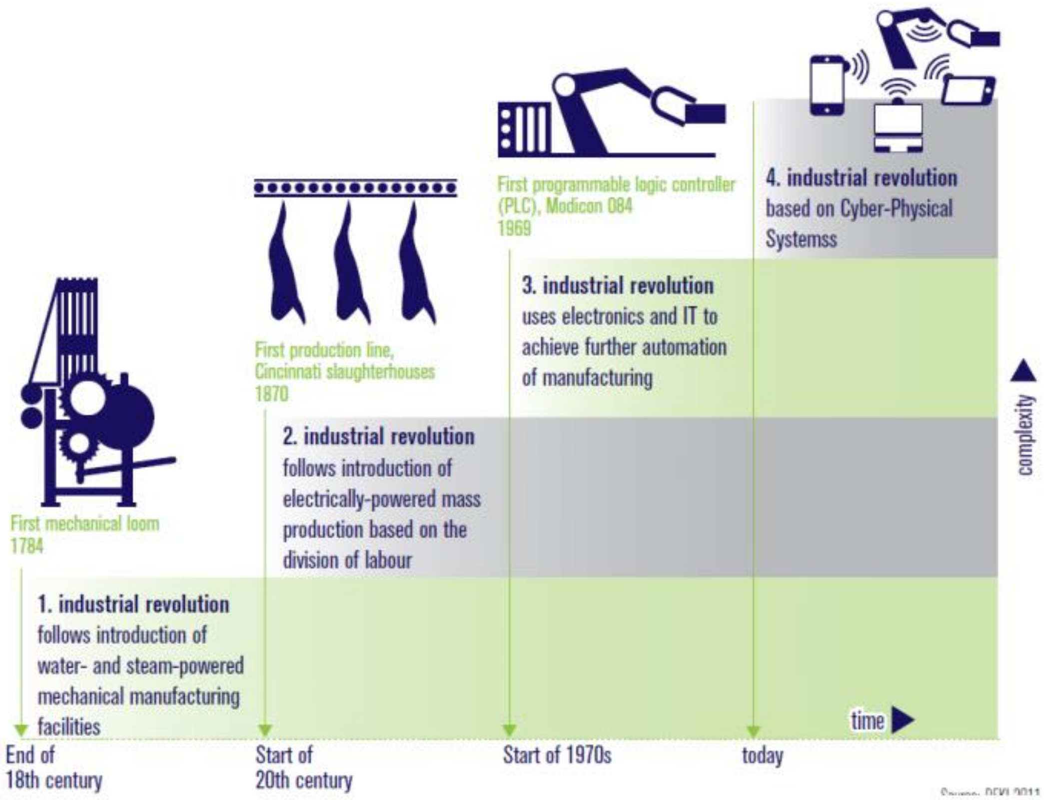

Figure 3-14 Industrial Revolutions (Kagermann et al., 2013)

Smart manufacturing will entail smart products being able to communicate with smart machines the manufacture them (Oberhaus, 2015; Weyer et al., 2015). The implementation of Smart manufacturing grounded on three central paradigms of Industry 4.0 which are Smart Product, Smart Machine and the Augmented Operator. The Smart Product is a work piece that is an active part of the system that receives information about the operational data and the requirements of its building plan. This allows the product itself to request the required resources and orchestrates the production processes for its completion (Kagermann et al., 2013). The Smart Machine paradigm describes the process of machines becoming Cyber-Physical Production Systems (CPPS)(Weyer et al., 2015). The Smart Machine paradigm will replace the traditional production hierarchy with a decentralised self-organising production system enabled by CPS. Self-organised machines will be able to communicate with local control intelligence and other field services, production modules and products through open networks and sematic descriptions. In this way, machines are able to self-organise within the production network. The Augmented Operator, which is the third paradigm mentioned shall provide technological support to the worker in the highly modular production systems. Weyer et al., (2015) argue that through the technological support human workers can realise their full potential and adopt the role of strategic decision makers and flexible problem-solvers. The Augmented Operator is presented by means of mobile, context-sensitive user interfaces and user-focused assistance systems (Jazdi, 2014).

Industry 4.0 also introduces to the concept of service oriented design. Service oriented design ranges from customers using factory settings to produce their own products to companies tailoring individual products for individual consumers (Kagermann et al., 2013; Oberhaus, 2015). In order to achieve the high product variability as well as a shortened product life-cycle as envisioned by Industry 4.0 an agile and flexible production structure is required. This level of flexibility cannot be achieved by traditional automation (Weyer et al., 2015). In order to meet the high levels of flexibility, modular structures composed of CPS systems and IoT are key to overcome the rigid planning and production processes (Dias, Diniz, & Hadjileontiadis, 2014). However, a high modular factory structure faces challenges of standardisation. The challenge and key of the success of the Industry 4.0 factory structure is dependent on multi-vendor and interoperable automated technology. The highly modular production structures should coordinate through standardised protocols and actions amongst the different relevant technology providers, integrators and end-users (Jazdi, 2014; Kagermann et al., 2013).

The SmartFactory initiative was established as a factory laboratory to address the challenge of standardisation as well as pave the way for interdisciplinary collaboration between various industrial companies and research centres (Jazdi, 2014; Weyer et al., 2015) (Figure 3-15). The SmartFactory is recognised as the first vendor-independent factory laboratory. Its purpose was to support the development , application and evaluation of innovative industrial technologies which embody aspects of Industry 4.0 (Weyer et al., 2015).

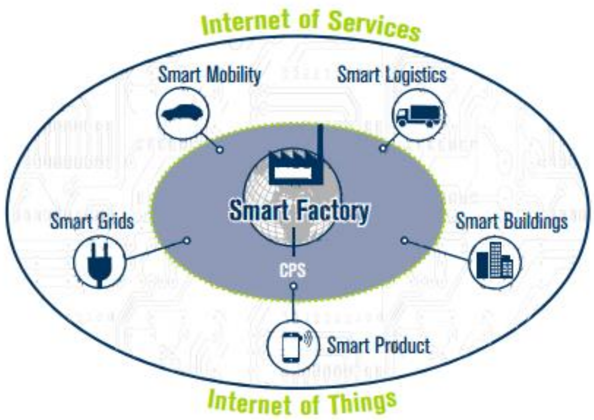

Figure 3-15 Smart Factory Initiative (Kagermann et al., 2013)

A strong network of automation technology providers defined a set of mechanical, electrical and communication standards amongst all vendor-specific subsystems in order address the issue of collaboration and interoperability within the factory structure. These standards have allowed technology providers to cooperate with other technology providers and researchers and provided an opportunity to test the interaction of the various components from different manufactures.

Industry 4.0 is an example of the impact and possible opportunities IoT will have on different economic sectors. Other sectors for example agriculture and smart living environments such as smart homes and smart cities have also taken to adopt the IoT paradigm(Borgia, 2014; Castro, Jara, & Skarmeta, 2013; Envirothon et al., 2014; Gubbi et al., 2013). The next section reviews the application of IoT in other economic sectors.

3.11. Analysis of Existing FSA Systems

The FSA market continues to evolve and mature in response to new technology developments in the areas of cloud-computing and mobility (McNeill et al., 2014; Sarkar, 2015). Gartner in the FSM Magic Quadrant report provide an analysis of the various field service automation software vendors such as ClickSoftware, ServiceMax and Orcale just to name a few. The report highlights that enable field service organisations to schedule and execute field service to support and improve overall service the strengths and weaknesses of the various market leading FSA software providers. The report evaluates each software provider based on the following four objectives offered by the vendor:

- Customer requests for a field service technician over the Internet, over the telephone or from an intelligent device;
- Scheduling and assigning of a service technician (long, midrange, weekly and intraday optimisation of the technician, factoring in assets and improved service level agreement [SLA] compliance);
- Complete mobilisation of that technician to perform end to end service tasks, including the ability to look up inventory status in real-time or cached on a wireless device; and
- Field service functionality that supports a variety of field service models including reactive, preventive, and predictive and reliability centred maintenance.

In their Magic Quadrant reports of 2014 and 2016 (McNeill et al. 2014; McNeill et al. 2016) Figure 3-16 and Figure 3-17 illustrate the leading FSM systems as identified by Gartner in 2014 and 2016 respectively. The systems are placed within the various quadrants based on their ability to execute the core functions of field service management and the completeness of the vision in becoming market leaders. In the sections to follow an evaluation some of the FSM systems identified within the Magic Quadrant report of 2014 and 2016 is performed.

Figure 3-16 FSA Magic Quadrant Report 2014

Figure 3-17 FSA Magic Quadrant Report 2016

3.11.1. Click Field Service Edge

ClickSoftware is the largest independent software vendor worldwide that offers field service optimisation (McNeill et al., 2014). ClickSoftware's field service products include ClickSoftware Enterprise Mobile Workforce Management, ClickExpress, ClickWorkforce and ShiftExpert on the Salesforce platform, and Click Field Service Edge. Click Field Service Edge is ClickSoftware's FSM management solution designed to improve the effectiveness and efficiency of after-sales field services in a service company. It aims at optimising all business roles from field staff to back-office users to top executives (Clicksoftware, 2015). Click Field Service Edge builds on more than 20 years of Clicksoftware's experience addressing field service organisations' needs. The solution delivers contextually-relevant, intelligent insights to users in real time to support service planning, scheduling, execution and analysis. Click Field Service Edge connects service technicians to the business and to customers with collaborative mobile tools that improve the experience for everyone. Employees benefit from real-time automation and intelligence delivered to the field, while customers receive appointment information and update notifications across multiple channels. At the core of Click Field Service Edge is an optimisation AI engine that provides intelligent recommendations for scheduling and dispatch based on a client's specific business policies. ClickSoftware has been a leading field service management vendor since 2013 according to Gartner's field service management quadrant report (McNeill et al., 2014).

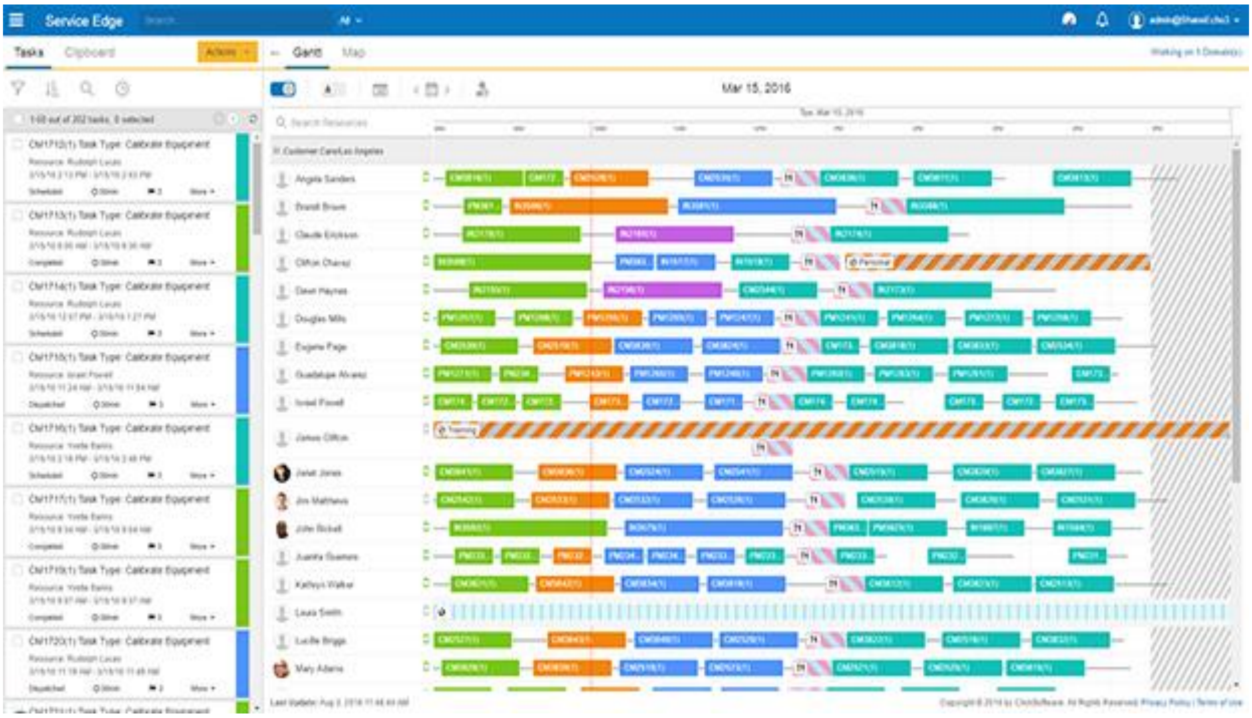

Figure 3-18 Click Service Edge(Clicksoftware, 2015)

3.11.2. Field Service Lightning by SalesForce

Salesforce is a new comer in the area of FSM. Salesforce introduced *Field Service Lightning* which is an integrated cloud based solution. Salesforce licensed parts of their new solution from ClickSoftware for hard components like scheduling and optimisation, then built the entire solution on top of Service Cloud. Field Service Lightning offers an integrated solution that eliminates the need to have data migration between different software packages, for example from a customer call centre module to a dispatch module and finally to a mobile application that is used by service technician in the field. Field Service Lightning promises a smooth transition from "phone-to-field" as mentioned by the senior director of product marketing and sales for the Salesforce Service Cloud package. Field Service Lightning logs a customer's call and generates a job card which is then transferred to a dispatcher (Figure 3-19). Upon receiving the job card the dispatcher is able to assign the job to the appropriate service technician using intelligent scheduling which performed by an AI programme called Salesforce Einstein. Salesforce Einstein assigns the job card to the appropriate service technician based on his/her proximity to the clients site, his/her experience for the kind of issue logged, the inventory on hand the service technician has and the relationship or prior experience the service technician may have with the particular customer. Furthermore, Salesforce Einstein provides an estimation of the time to be taken to resolve the problem based on the information logged from the customers call and a plausible solution. Upon completion of the job cards analysis the selected service technician receives the job card via a mobile application that he or she has access to in the field in real-time.

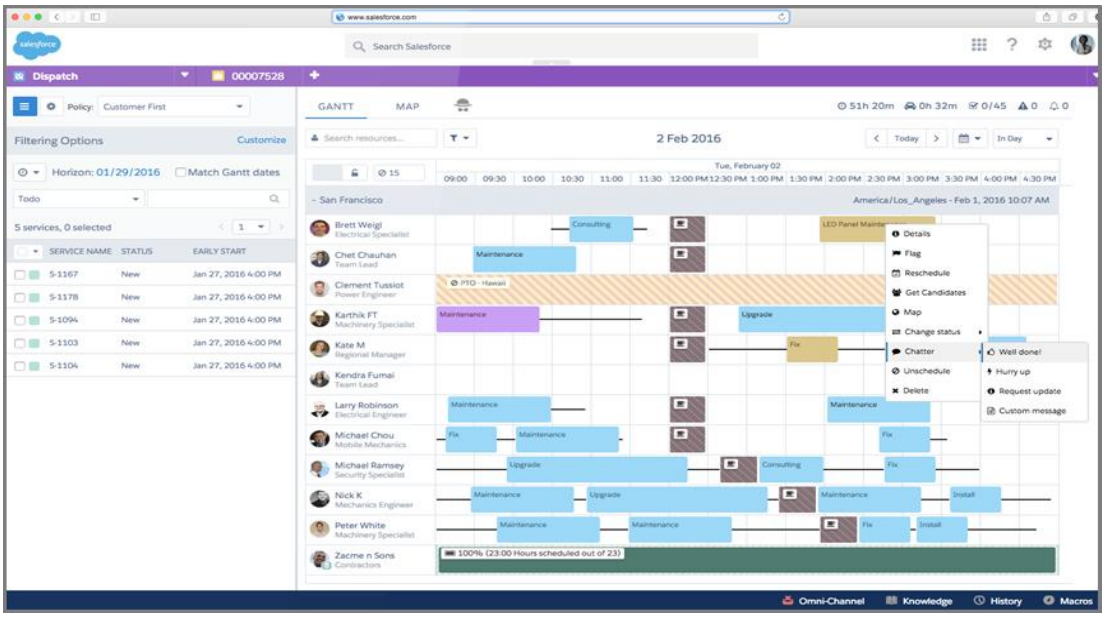

Figure 3-19 Field Service Lightening Dispatch Console (Salesforce, 2015)

3.11.3. ServiceMax

ServiceMax has been a pioneer in the adoption of cloud solutions within the field service management sector (McNeill et al., 2014). ServiceMax has a business model focused on offering Software-as-a-Service (SaaS) and hence their focus on cloud based solutions. (Advice Software, 2015). ServiceMax solution is an integrated suite of applications aimed at optimising managing employers and customers. The solution offers five core field service functions contracts, scheduling, inventory management, social collaboration and customer service. Customer contracts can be accessed through a web platform by employees within the field and those at the service organisations premises. The contracts are available in user-friendly formats to ensure information can be interpreted accurately. Inventory management has features that help track parts, returns and repairs a service technician has on hand. ServiceMax offers a unique set of tool and applications that are not common to most field service software (McNeill et al., 2014). ServicePulse a social platform that is available to ServiceMax employees within the field. ServicePulse allows a service technician to be in contact with other service technicians and industry experts whom can aid the technician to address a challenging problem whilst in the field. ServicePlus allows the technician to open a virtual chatroom in real-time while they maybe at a customer's facilities. Additionally, ServiceMax offers customer service teams the ability to monitor customer activity by keeping up-to-date on any known issues that might arise in the field. ServiceMax offers a broad service suite in several editions: Express, Enterprise and Unlimited.

3.11.4. FieldOne

Microsoft acquired FieldOne Systems in 2015 in order to gain market share in the ever growing field services sector(Stutz, 2015). FieldOne is a service management platform that provides large and enterprise field service companies with tools to streamline their business processes. FieldOne offers real-time mobility across devices, automated routing and workflow automation. FieldOne can be used by both large and small-to-medium sized service providers. FieldOne is a cloud-based platform that is developed on the Microsoft Dynamics Platform. This gives FieldOne the added benefit of inheriting Microsoft's multi-language, multi-currency and time-zone support. Utilising the Microsoft platform provides a wide range of third-party plug-and-play extensions, as well as scalability and integration points. FieldOne has an integrated automated routing engine, WEB portals, Integrated Voice Response (IVR) and a centralized mobility management platform.

3.11.5. Comparison of FSA Systems

The existing systems reviewed enable field service organisations to schedule and execute FSM product activities to support and improve overall service. The systems reviewed are leading software within the FSM sector (McNeill et al., 2014). Cloud-computing and mobile technologies are common features offered by the vendors. Cloud based solutions allow field service organisations to manage activities at a lower cost, with high reliability and enhanced maintenance capabilities (Buyya et al., 2010). Mobile technologies allow field technicians to access service information, such as service history of equipment being maintained or repaired, whilst they are in the field. With a combination of cloud-computing and mobile devices service technicians can get real-time access to information as needed (Advice Software, 2015; Clicksoftware, 2015). In order to optimise activities such as dispatching and scheduling of service technicians as well as the forecasting average service time, systems such as SalesForce and ServiceMax make use of AI algorithms. The systems evaluated aided in identifying the requirements of an FSA system that addresses some of the challenges faced by field service organisations such as scheduling and access to real-time information.

The systems evaluated all follow the traditional field service process with the service being initiated by a customer logging a service call. In an era of devices being able to connect to the Internet none of the FSA vendors provide a solution that communicates directly with Original Equipment Manufacture's (OEM) devices or systems. If service providers could directly interact with OEM's systems or devices the field service process would be initiated by the device and not the client. Table 3-8 summarises the systems highlighting the key features that they offer and some of the shortcomings they possess in addressing field service challenges identified.

Table 3-8 Summary of FSM Existing Systems

FSM System	Click Soft Edge	ServiceMax	FieldOne	Field Service Lightning
Cloud-computing	✓	✓	✓	✓
Mobile Technologies		✓	✓	✓
Intelligent Systems		✓	✓	✓
Other features		✓	✓	Compatible with Microsoft products Automated routing
Shortcomings	No interface with OEM systems.	No interface with OEM systems.	No interface with OEM systems.	No interface with OEM systems.

3.12. Conclusions

This chapter addressed the first activity of the DSRM, namely Problem Identification and Motivation (Section 2.3.3). The problems of FSM (Section 3.2) and its KPIs were identified (Section 3.3). Information inaccuracy and its lack of real-time access are amongst the problems identified that hinder efficient delivery of field services. FSA optimises field service delivery through automated dispatching of field technicians and remote monitoring. However, current FSA techniques do not adequately address information inaccuracy and its real-time access.

An IoT promises to bring tangible benefits to the environment, the society, individuals and business with the creation of new intelligent applications, services and products in various domains whilst ensuring the protection and privacy of information and content exchanged. The growth of IoT is being driven by advancements in technologies such as WSN, cloud-computing, Big Data Analytics and IPv6. However, the IoT faces challenges in the standardisation of networks and system designs, management of data and security. Security and big data pose challenges that may hinder the realisation of the IoT vision. Furthermore, more the IoT standardisation needs to be implemented in order to accelerate the role out of IoT solutions in various application domains.

The implementation of an IoT has been described by means of a layered architecture as well as data a flow architecture. The IoT is a technology that can improve field services due to its ability to provide real-time and quality data that can be used by field service organisations to minimise downtime through the rapid response to issues detected and the possibilities of predictive maintenance of equipment within the field.

This chapter fulfilled the following research objectives, namely:

- RO 1. Identify problems faced by after sales field service organisations.
- RO 2. Identify the technologies that can be used to optimise FSA and enable the growth of the IoT.
- RO 3. Identify the problems associated with the IoT.

The next chapter shall review findings from interviews conducted in order to establish problems within the real-world context of FSA. Furthermore, the design process and the proposed IoT model for FSA will be presented.

Chapter 4. FSA in a Real-World Context and the IoT Model for FSA

4.1. Introduction

The previous chapter discussed the literature studies on the problems faced by after sales field sales organisations as well as identifying the KPIs of FSA. IoT was identified as a technology phenomenon that could optimise field services. This chapter reports on the first, second and third activities of the DSRM process the identification of the problem, defining the objectives of the solution and the design of the artefact respectively (Figure 4.1).

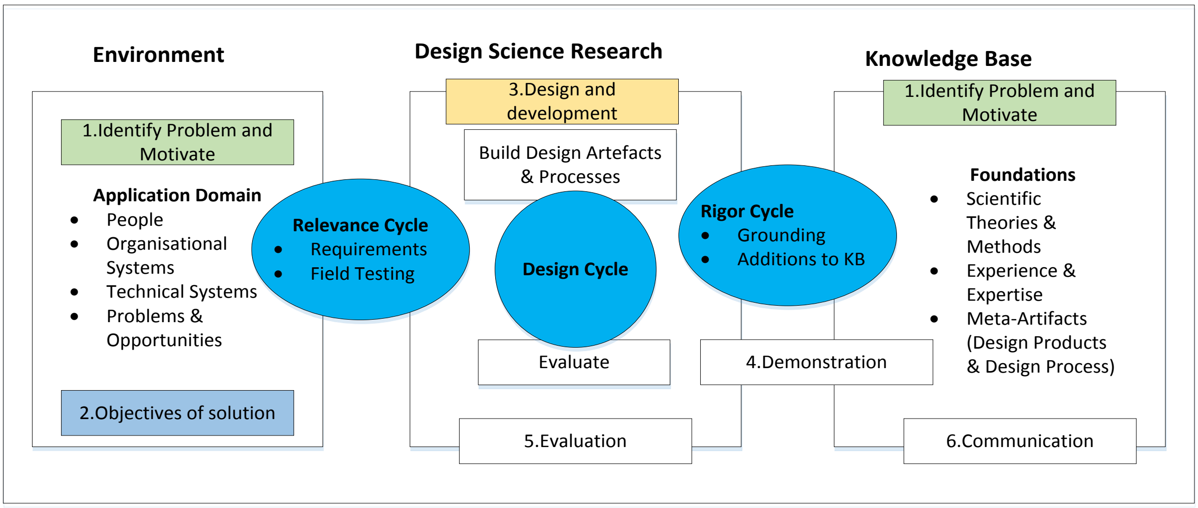

Figure 4-1 Chapter 4 Activities in Adapted DSRM

The following three research questions of this study:

- RQ 1. What problems are faced by field service organisations providing after sales services as identified by literature and within a real-world context?
- RQ 4. What are the requirements and objectives of an IoT-based FSA system?
- RQ 5. How should a model to support optimisation of FSA be designed?

The chapter begins by revealing the process undertaken in designing the proposed artefact (Section 4.2). Then in order to determine a real-world context of the problems faced by field services interviews will be conducted with industry experts (Sections 4.3). The environment in which the case study falls shall also be reviewed and an interview shall be conducted with a stakeholder within the case study (Section 4.4). The objectives (Section 4.5) and requirements (Section 4.6) of the proposed prescriptive model were established and discussed. The requirements and objectives identified laid a foundation for the design of the proposed model. A detailed description of the model and its components shall be then be conducted (Section 4.7). Figure 4-2 illustrates the structure of this chapter.

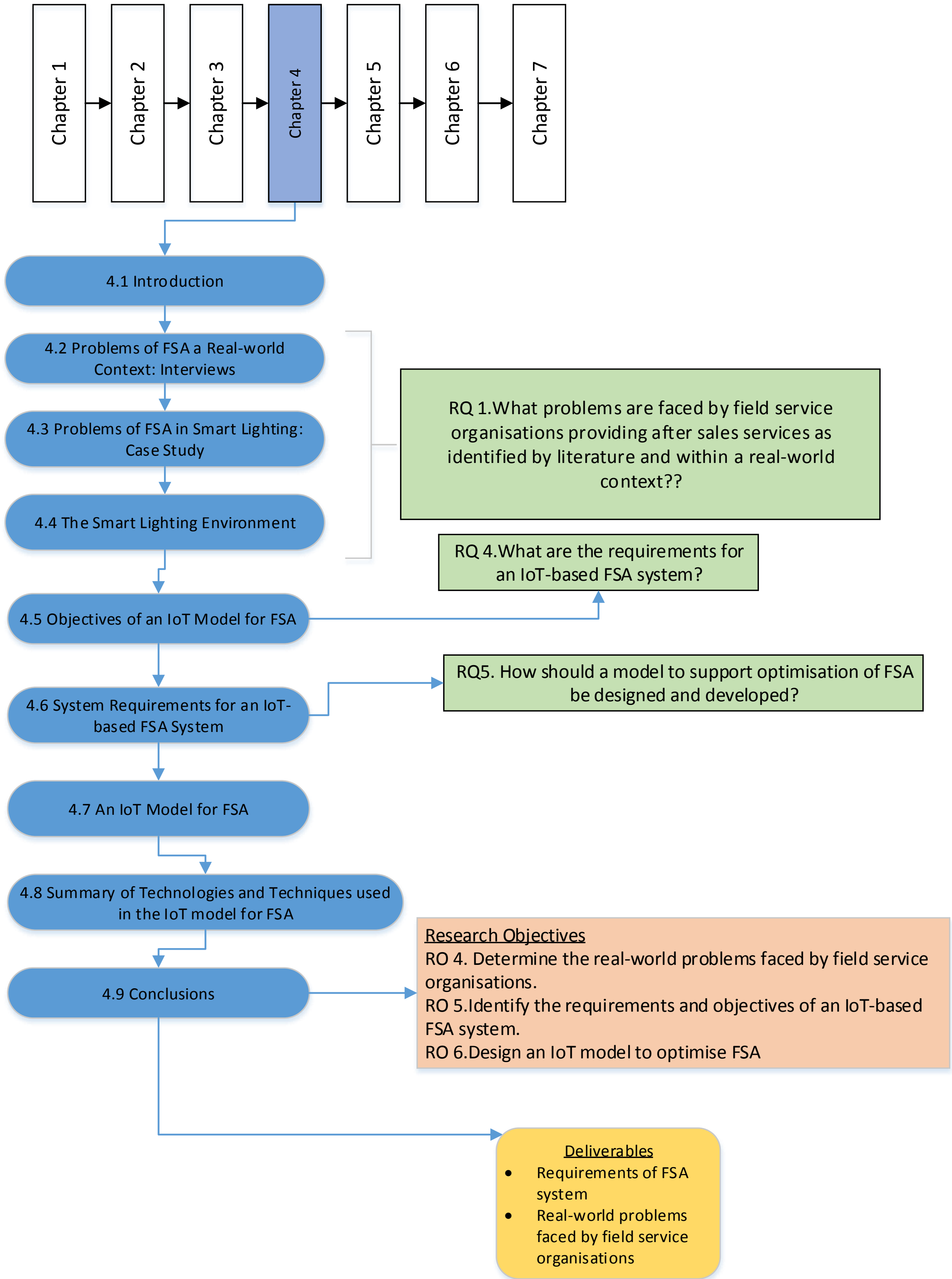

Figure 4-2 Chapter 4 Structure

4.2. Artefact Design Process

The challenges faced by after- sales organisations have been identified by means of a literature study. In order to explore the implications for real-world practitioners, this researcher also conducted interviews with experts in the after-sales field service sector. This process, as well as the findings that emerged from it, are discussed in Section 4.3. The literature study helped the researcher to identify the problems faced by practitioners in after-sales field services. As established in Section 2.3, DSR aims at addressing the problems in practise using an artefact. This researcher will suggest the use of a prescriptive model to create an artefact that aims at addressing the problems encountered in the practise of after-sales field services. An analysis the existing FSA systems has contributed to an understanding of the KPI requirements of an FSA system (Section 3.11). The literature study also aided in identifying the IoT as a plausible technological phenomenon that can be used to address the problems within the after-sales service industry. By identifying the problems faced by field services, as well as the requirements of FSA, the researcher addresses RQ 5, which is:

RQ 5. How should a model to support optimisation of FSA be designed?

The model design and development process, incorporating the processes of information gathering from the literature study, the interviews and an analysis of existing systems, is depicted in Figure 4-3.

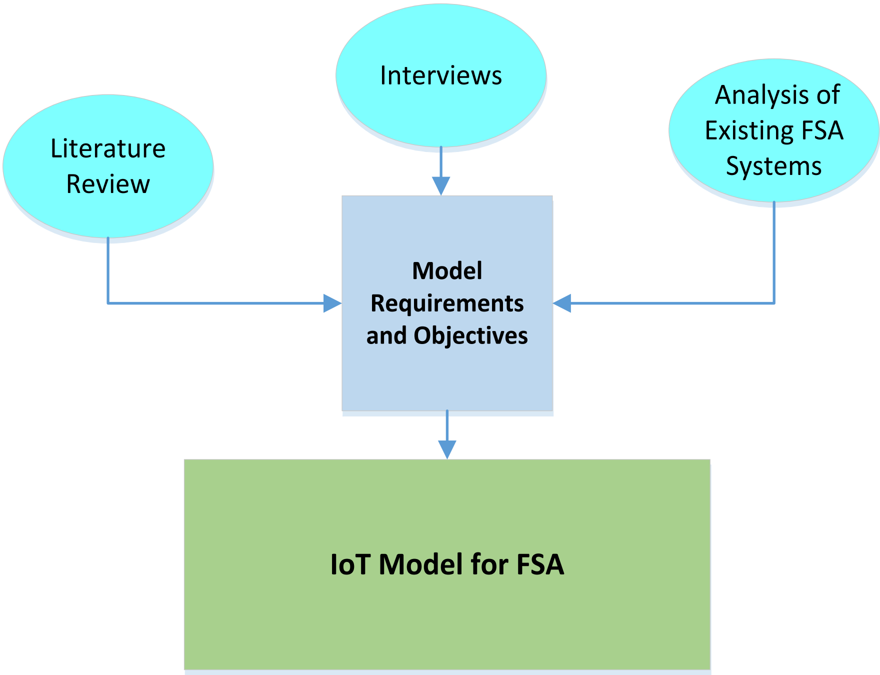

Figure 4-3 Design Process of IoT Model for FSA

In accordance with Hevner's (2007) three-cycle view of DSR, two of the three cycles, the rigour and relevance cycles, have been undertaken and lead to the design cycle. The rigour cycle described in the literature review identified challenges faced by the after-sales field service industry. During the rigour cycle, different technological trends are identified that could aid in optimising field services, and the IoT is identified as the ideal technological solution. The relevance cycle consists of the interview findings and the results of an analysis of the existing systems. The interviews and the analysis of the existing systems will provide the relevance cycle with the research requirements from an environmental perspective. With input from the rigour and the relevance cycles, the construction of the artefact shall be performed during the design cycle. Figure 4-4 summaries the application of the DSR three cycle view thus far in this research.

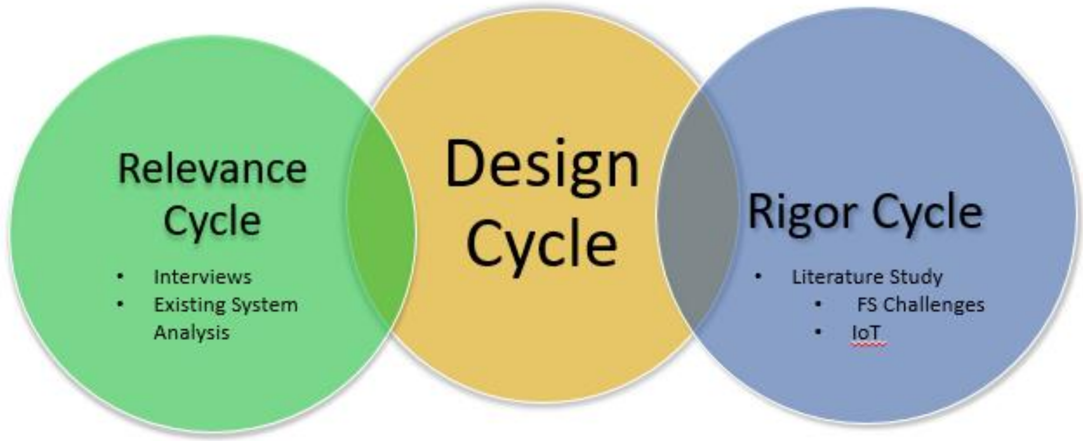

Figure 4-4 DSR Three Cycle View (Authors Own Construct)

4.3. Problems faced by FSA in a Real-world Context: Interviews

The aim of the interviews as well as a description of the participant profiles of the participants will be discussed in this section. The section also presents the findings of the interviews conducted with managers and artisans.

4.3.1. Aim of Interviews and Participant Profiles

Interviews are one of the most widely-used data generation methods, according to Johannesson and Perjons (2012b), and are one of the research methods used in this study. The interviews were conducted after a review of the literature, as suggested by Sobh and Perry (2006). The findings of the interviews will contribute, not only to identifying the problems faced by the field service organisations in question, but also to confirm the reality of the problems identified in the literature. Prior analysis of the literature assisted the researcher in structuring the interviews and allowed him to be an active participant during the interviews (Sobh & Perry 2006). The knowledge gained during the literature review also assisted the researcher in the selection of the interview participants (Peffers et al. 2007). Semi-structured interviews were conducted with industry experts within the domain of after-sales field services. The interviews were conducted face-to-face and remotely via telephone. The interviews conducted consisted of participants from three different organisations which offer after sales services within their various industrial domains. The organisations consisted of a specialised consultancy firm that offers a system implementation and design consultancy services for organisations which manage technicians that offer after-sales field services. The second organisation is a department within a higher education institution (HEI) which is responsible for the delivery of after-sales field services within the HEI. The researcher selected the department as it not only met the definition of an after-sales field service organisation and the department proved to be a convenient source of data for this research. The third organisation was the consultancy firm that developed the smart lighting system used within the case study. The interviewees consisted of five participants who were categorised into two groups, namely supervisors/managers and artisans.

The two managers interviewed each had at least 10 years' experience in the field services domain and had held managerial positions for at least three years. The first managerial participant, P1, is currently employed by Accenture South Africa and has been involved in multiple field service optimisation projects. The second managerial participant, P2, is the Deputy Director of the Maintenance Services department within a higher education institution (HEI). The three artisans interviewed are all members of the HEI's Maintenance Services department. Two of the artisans interviewed are electrical technicians, and the third works as a mechanical technician. The artisans each have at least 10 years' work experience in the field, providing services such as repairs, maintenance and installations. Participant 3, P3, holds a Bachelor in Technology degree (specialising in Electrical Engineering) and has 15 years' experience in the field services domain. Participant 4, P4, holds a Master's degree in Technology (specialising in Electrical Engineering) and 17 years' work experience. Participant 5, P5, holds a Diploma in Mechanical Engineering and 10 years' experience in the field services domain. Table 4-1 summarises the participant's profiles.

Table 4-1 Participants Profile

Participant	Position held	Work Experience	Qualification	Field Services responsibilities
Managers				
P1	Senior Manager Accenture Telecommunications and Technology	7 years	Honours Degree Information Technology	Project management FSM system design
P2	Deputy Directors HEI Maintenance Services	15 years	BTech Electrical Eng ND Electrical MBA	Project Management Repairs Maintenance Installation Supervisor Dispatcher
Artisan				
P3	Artisan HEI Maintenance Services	15 years	ND Electrical BTech Electrical	Repairs Maintenance Installation

P4	Artisan HEI Maintenance Services Supervisor	17 years	ND Electrical BTech Electrical MTech Electrical	Repairs Maintenance Installation Supervisor Dispatcher
P5	Artisan HEI Maintenance Services	7 years	ND Mechanical Eng	Repairs Maintenance
P6	Senior Engineer engineering consultancy firm	2 years	MEng Mechatronics	Installation Repairs

The interviews were conducted in a semi-formal structure to allow the participants to also lead the conversations and add their input (Johannesson & Perjons, 2012). Analysis of literature found that there are several problems of FSA (Table 3-1). The researcher made use of the problems identified in literature as a baseline for the problems faced by not only field service technicians (Section 3.2) but also the service technicians. An analysis of the interview findings provided by the technicians and the managers shall be discussed in the following sections.

4.3.2. Interview Findings: Managers

Semi-structured interviews with two (n=2) managers P1 and P, were undertaken to attain a high-level overview of FSA within field service organisations and to identify requirements of FSA systems. Managers were also interviewed to identify problems associated with automation and management of field services. Additionally, the managers aided in identifying the problems from an organisational view. The interview questions posed to the managers were of a technical nature (Section 1.7). The market related and managerial related questions were not asked as addressing them is out of this research. The managers were asked questions in order to provide structure for the semi-formal interviews conducted. An analysis of the interview responses is provided in this section.

Question 1: Are there any problems around information access or delivery of field services?

When the participants were asked to identify problems relating to information access or delivery of field services the lack of access to information was identified that is PB8 (Table 3-1). Access to information relating to the equipment being serviced was a common challenge identified by both participants within this category. According to participant P1 *"…The lack of end-to-end view of by service providers is due to the lack of access to information*". P1 alluded to the inability of service providers to provide the technicians with mobile devices as an example. Furthermore, P1 stated that "..*There is lack of endpoint connection to a client's equipment to access real-time information.*

For example, some field service providers to not have direct access to the client's OEM's, therefore, unable to gain real-time notifications to faults. However, this is specific to industries for instance the Telecommunication industry provides endpoint connection in general". P2 identified the lack of access to historical data as a challenge. The participant made the following statement when asked about the problems around information access or delivery of field services: "*Lack of historical data to determine root causes of equipment failure is a challenges we are currently experiencing. We are unable to determine if a fault is reoccurring. If we could identify reoccurring faults then we could be able to make better decisions in terms of parts procurement. The Computer Maintenance Management System (CMMS) lacks customisation to be able to track historical data" .*Participant P2 stated that the availability of historical data to service technicians when they are in the field, would enable them to efficiently rectify reoccurring equipment faults.

The historical data needs to be accurate and reliable for the service technician to successful carry out his/her service tasks. Participant P2 highlighted the inaccuracy of information about equipment as a barrier in the efficient delivery of the service. For instance, when a service technician is on call to repair faulty equipment such as an industrial air conditioner, inaccurate information about the equipment could cause the technician carry the incorrect service parts. The provision of accurate information is key in the management of customer expectations according to participant P1. Customers expect the service provider to have accurate and detailed information about the equipment for the service provider to efficiently provide a remote diagnosis.

Question 2: Name of any FSA tools used?

The participants both made use of FSA tools within their organisations. Participant P1 made use of Oracle Field Services Cloud, formerly called TOA technologies. Whilst participant P2 made use of a customised Building Management System within his organisation. Oracle Services Cloud allowed for the real-time access of information by service technicians on their mobile devices supplied to them. However, the system only provides the service technician with information once it has been approved by a dispatcher. Therefore, not providing an end-to-end fully integrated system that allows the service technician to interact with the faulty equipment remotely before getting on-site. The Building Management system operated by the HEI enables remote monitoring and controlling. However, service technicians do not have access to the system, only the supervisor and participant P2 have access to the system.

Question 3: Are there any other challenges related to FSM and FSA in your organisation not mentioned yet?

This question was based on the problem identified in literature namely PB4 (table 3-1). The participants identified other challenges such as the lack of integration between the ERP system and the Work Flow Management system and the Building Management System. Lack of education on the consumers' equipment by the service technician was another challenge identified by P1 that hinders the delivery of after sales field services. Participant P1 stated the following *"..There is generally a lack of an end-to-end view of service provision by service providers which is a barrier to the critical success of efficient and effective service delivery*". Apart from identifying problems with FSA within their organisations and other field service organisations the managerial participants also identified functionality they would require in an FSA to optimise service delivery.

Question 4: Should job cards be linked to the purchasing and accounting system? To request for quotes based on the repairs required?

The final question asked to the participants related to the need of integration of the FSA with the purchasing and accounting systems. This question was based on the lack of integration of enterprise systems that is PB4. The second participant gave the following response "*It would be ideal, however the current university system, ITS, is suited for the university environment. A maintenance module that can, however, be purchased but it would also require customization to allow for the integration – further increasing the costs*. An ERP system would be more suitable, such as SAP". Participant P2 proposed an FSA system should be able to send job cards and preventative maintenance schedules to artisans via mobile devices whilst they are in the field. The use of mobile devices by service technicians would allow them to view historical data about the equipment when servicing it. The historical data would inform the service technician on what maintenance or repairs have been performed on the equipment. The data should be specific to specific equipment and should be updated once maintenance or repairs have been performed.

Question 5: What additional functionality would ideally make your work easier?

When asked what additional functionality the participants would make their work easier participant P2 stated that ..*" All job cards and preventative maintenance schedules to be sent to the field device of the artisan. They should be able to see the history of the equipment when servicing it. To establish what maintenance or repairs have been performed. This will allow for the* *preventative maintenance system to establish the useful life of the equipment to assist it lowering of costs.*

Thus, to develop artificial intelligence working on top of the system to facilitate a number of tasks that would require many people to accomplish – such as data analysis. " .

The participant also identified the need for analysis of data collected by the FSA system. Data analysis by an AI system would facilitate tasks such as automatic scheduling and fault identification according to P2. The participant concluded by stating that such an FSA would allow management to monitor the estimated usual life of equipment which could lead to cost reduction by means proactive action rather than corrective action. That would be able. Participant P1 identified the need to have an integration of systems between ERPs and FSAs (PB4). He stated that this would allow for planning, forecasting and scheduling of the workforce. Furthermore, such a system would provide service providers with an end-to-end view of service operations. Table 4-2 provides a summary of the interview findings.

Table 4-2 Managerial Interview Findings

Problem	Type	Participant
PB 10: Inadequately educated service technician on consumer products (new)	Managerial	P2
PB 12: Lack of end-to-end view by service providers (new)	Technical	P1
PB 13: Limited access to information by service technicians- no mobile devices (new)		P1,P2
PB 14: Lack of equipment historical data provision (new)		P2
PB 4: Lack of integration between enterprise systems and FSM systems e.g. ERP,WFM		P1,P2
PB 7: Down-time management	Managerial and technical	P1, P2
PB 8: Inaccurate information	Technical	P1,P2

After conducting interviews with the managerial participants, the researcher requested to interview the artisans within the HEI Maintenance department. The findings from the interviews conducted shall be discussed in the next section.

4.3.3. Interview Findings: Artisans

Structured interviews were conducted with three artisans which consisted of a question and answer session. The purpose of the interviews was to establish the nature of the day to day activities performed by the artisans. The problems as identified by literature were verified by means of a Likert scale. The service technicians were also asked open-ended questions in order to identify other problems not identified in literature. The question and answer session allowed the researcher to verify or refute previously identified problems as well as new, unidentified challenges as proposed by Johannesson & Perjons (2012).

The first part of the interview was a question and answer session. The participants were asked questions relating to the problems they have encountered during field service delivery and management. Four of the problems were identified from the literature study (Table 3-1) were confirmed during the interview session with the artisans. Findings from the question and answer session relating to the problems are summarised in Table 4-3.

Table 4-3 Problems Identified by Artisans

Problem	Participant P3	Participant P4	Participant P5
PB2: Customer demand and high expectation	Moderate problem	Extreme problem	Moderate problem
PB5: Real-time Communication (RTC)	Moderate problem	Somewhat problem	Somewhat problem
PB7: Information Inaccuracy	Extreme problem	Moderate problem	Extreme problem
PB9: Availability of resources on site	Moderate problem	Moderate problem	Moderate problem
Other problems	None identified	Service technicians inadequately informed on equipment to be serviced	Lack of uniform maintenance of equipment after initial installation

The artisans were also about the types of maintenance they perform within the organisation. The types of maintenance identified by literature were preventative maintenance, corrective maintenance and predictive maintenance. The artisans verified the performing preventative and corrective maintenance activities. However, they all stated that predictive maintenance is not carried out within their organisation. When asked if they believed that predictive maintenance would optimise service delivery in their organisation they all were of the belief that it would. The artisans identified the lack of use of mobile technologies in the execution of tasks as a challenge.

The interviews confirmed seven of the problems faced by service organisations as identified by literature (Table 3-1). The interviews also highlighted one additional challenge that was not identified by literature that is an end-to-end view of service operations and lack of integration of enterprise systems, such as ERPs, and FSA systems. Table 4-4 provides a summary of the consolidated problems faced by field service organisations as identified by literature and the interviews

Table 4-4 Consolidated Problems in FSM

Problem	Literature Study	Interviews
Managerial		
PB2: Management of customer expectation	✓	✓
PB10: Inadequately educated service technician on consumer products (new)	×	✓
PB11: Lack of uniform maintenance of equipment after initial installation	×	✓
Technical		
PB4: Lack of integration between enterprise systems and FSM systems	✓	✓
PB5: Access to real-time information	✓	✓
PB7: Downtime management	✓	✓
P12: Lack of end-to-end view by service providers	×	✓
PB13:Inadequate use of mobile technologies by service technicians	×	✓
PB14: Lack of equipment historical data provision	×	✓
Management and technical		
PB7: Downtime management	✓	✓
PB8:Information Inaccuracy	✓	✓
PB9: Availability of resources on site	✓	✓

The second part of the interview session related to the characteristics of the tasks they perform. The artisans all performed the field service tasks as identified by literature (Agnihothri et al., 2002) which includes repairs, installation, and maintenance. However, the frequency of the tasks performed differed with each artisan due to the different responsibilities they are responsible for (Figure 4 2). For instance, participant P4 is a supervisor and an artisan and therefore does not go out in the field as often as he also has administrative duties to perform. The second question related to the time spent on performing repair tasks. The responses showed that on average, repair tasks take between six to eight hours to complete. Regarding time taken for installation, the three participants stated that this was heavily dependent on the type of installation being performed, and all three participants recorded three different results that ranged from less than two hours to between two hours and more than five days. For maintenance tasks, the participants recorded an average of six to eight hours to complete.

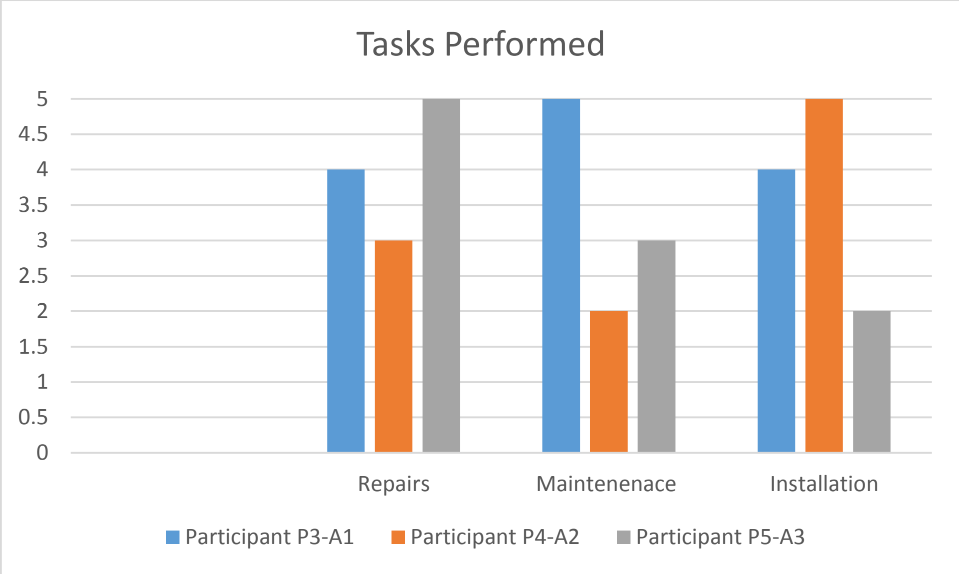

Figure 4-5 Tasks Performed

The use of a literature study and interviews with industry experts in establishing problems faced by field service organisations were successful. Therefore, an examination of literature and interviews were also used for information gathering in the context of the case study. The case study was on a company delivering after sales services to an organisation implementing smart sighting systems. The following section discusses the case study and the challenges faced by the organisation delivering after sales field services. The discussion also includes the effect IoT may have on FSA is applied to the case study.

4.4. The Smart Lighting Environment

The smart lighting environment shall be reviewed in this section. The various components of the smart lighting environment shall be identified. Once the background of the smart lighting environment was established the problems faced within the context of the case study were revealed through the findings of an interview conducted. The interview was conducted with the service technician responsible for the maintenance and repairs of the smart lights. The case study, problems and interview are discussed in this section.

4.4.1. Overview of Smart Lighting Environment

In order to conceptualise the impact of the IoT within FSA a real-world example of a smart city ecosystem that has been implemented in the smart lighting industry will be considered. A smart city is an urban development that envisions the efficient management of a cities resources and services with the use of integrated information and communication technology solutions (Castro et al., 2013). The resources and services of a smart city include, but are not limited to utilities, that is water supply, electricity and waste management, hospitals, schools, transportation systems and other community services. Smart cities play an important role in the sustainable economic development of countries or states seeking to attain environmental sustainability. The reduction and efficient management of energy consumption is a way in which a municipality can take a step towards sustainability. With the drive for better energy management within cities, there are various initiatives that various municipalities are undertaking, for example, the implementation of smart lighting projects (Castro et al., 2013).

Lighting is responsible for an estimated 19% of global use of electricity usage and accounts for 6% of greenhouse gasses total emission (International Energy Agency, 2015). In the context of cities, street lights are one of the most important assets to maintain and control as they provide safe roads, enhance security for homes, businesses and city centres. However, street lights are very costly to operate and account for an estimated 40% of the amount of electricity spent in an urban city (Basu et al., 2014). Therefore, this factor with the rising electricity costs is ever becoming more crucial for the day to day budgeting of municipalities. To address these issue, city managers are implementing smart lighting solutions.

Smart lighting consists of heterogeneous and multidisciplinary areas of lighting management, with the possibilities of integrating a wide range of sensory and control technologies. The integration of the sensory and control technologies with information and communication systems can achieve high efficiency and lower the negative impact derived from the use of energy for illumination, in combination with intelligent functionalities and interfaces of lighting in the ambient, commercial and public domains (Castro et al., 2013; Koh, Tan, Wang, & Tseng, 2011).

Smart lighting as discussed by Castro, Jara and Skarmeta (2013) compromises of the integration of intelligent functionalities and interfaces at four complementary levels (Figure 4-6). The four levels are the embedded level, system level, grid level and communications and sensing levels. The embedded level is the lighting engine or the light itself, whilst the system level is the luminaries and lighting systems. The grid level compromises of the management and monitoring of the power sources, energy generation and plants and the distribution of utilities and appliances. The final level is the sensing and communication level which compromises of the monitoring, control and management of the applications this can also be referred to as the application /services level.

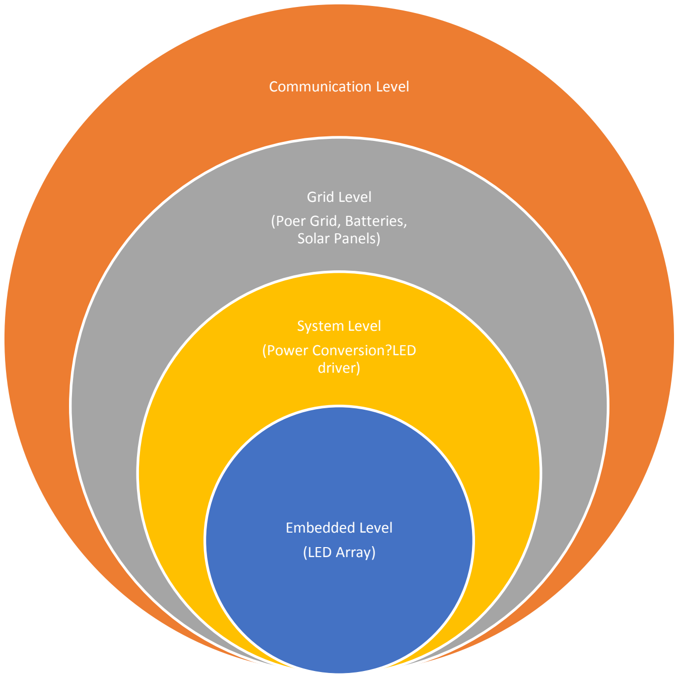

Figure 4-6 Smart Lighting Integration Levels (Castro et al., 2013)

As can be noted from a technology point of view the smart lighting system and the concepts of an IoT are closely related, since each smart light within the smart lighting system may be regarded as a “smart thing” within an IoT ecosystem. Furthermore, the layered architecture of a smart lighting system is similar to that of an IoT layered architecture with the application and services layer being the outermost layer in both structures. Therefore, for this research, the smart lighting system will be used as an example of an implementation of an IoT ecosystem.

4.4.2. Smart Lighting in Case Study

Components and features of the smart lights within the smart lighting system under consideration in this study contain a wind turbine and solar panels for energy generation and contain a battery pack for energy storage. Each smart light is uniquely identifiable and has both computational and communication capabilities. The architecture of the smart lighting system allows for remote monitoring. The smart lighting system is maintained an engineering consulting organisation within the HEI. The engineering consulting organisation provides maintenance and repair services for the smart lighting system. An interview was conducted with one of the senior engineers at consulting organisation in orderto establish an overview of the environment as well as the challenges faced by the organisation in delivering services for the smart lighting environment.

The smart lighting environment consists of numerous smart lights that are used as outdoor luminous equipment for parking bays and security lights for building facilities. The smart lights are grid independent lighting equipment. This means they are not connected to a local or municipal electricity provider for the energy needed to light the LED lights. The smart light makes use of two energy sources that is a wind turbine and a solar panel. An on board 48 voltage battery pack is used as an energy storage unit. The solar panel is used to harness solar energy and a wind turbine that generates electricity by the turning of a generator. The smart light also contains sensors and actuators which enable it to measure environmental variables and respond to specific conditions by means of the actuators. The sensors include ambient sensors on the solar panel, voltage and current sensors on the circuit board of the smart light. Furthermore, the smart lights also contain onboard microcontrollers that provide computational and communication capabilities (Figure 4-7).

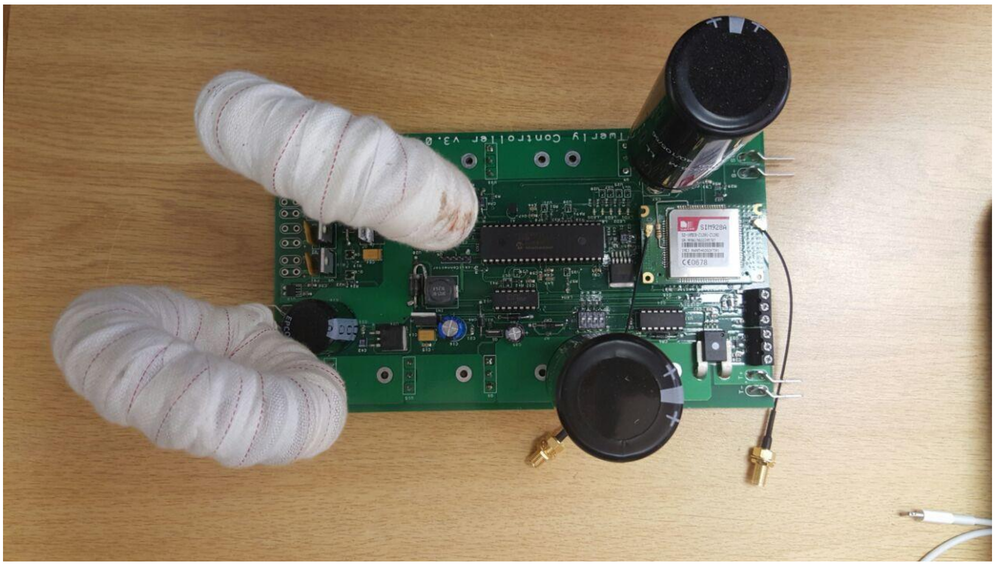

Figure 4-7 On-Board Arduino Microcontroller

The micro-controller receives voltage and current data readings from the solar panel and wind turbine. It also records the voltage and current that is outputted to the LED light. Voltage and current data readings to and from the battery management system, which manages the flow of current to the battery, are also recorded. Once the various readings have been recorded they are then sent to a remote server for processing. The flow of data within each smart lighting system is shown in Figure 4-8.

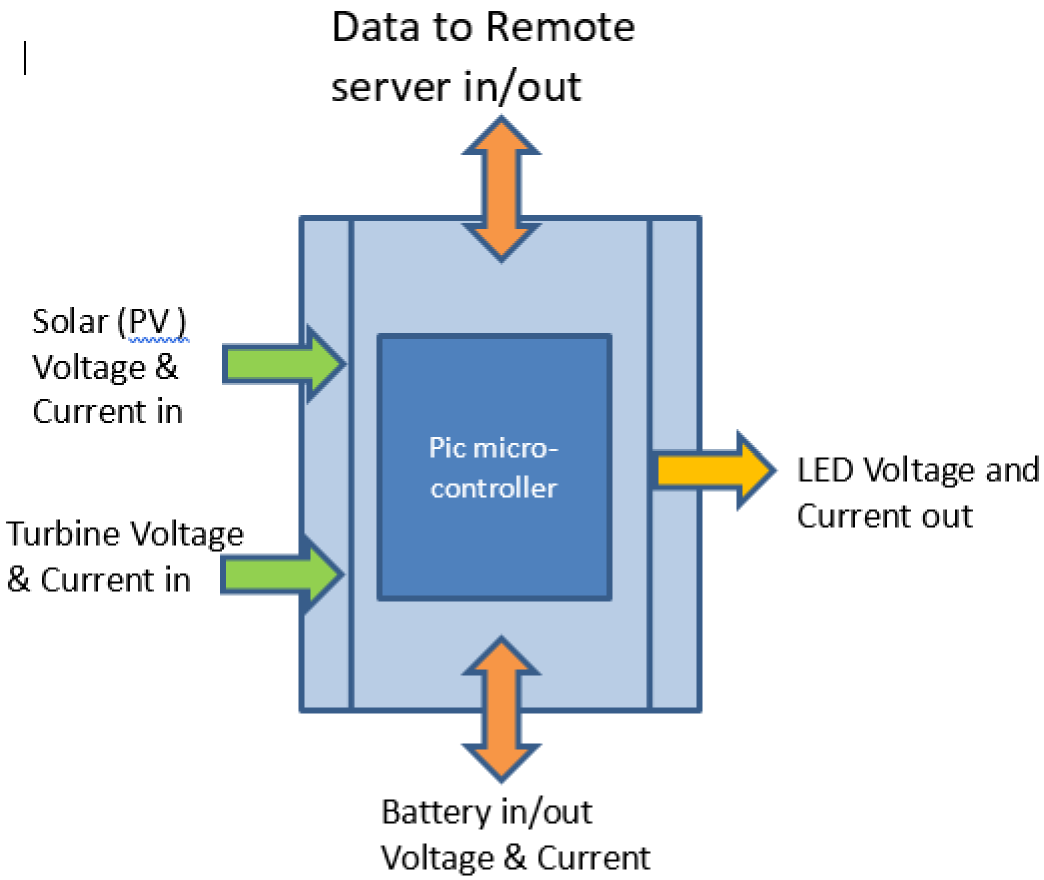

Figure 4-8 Data Flow within Smart Light (Authors Own Construct)

4.4.3. Problems in Smart Lighting Case Study: Interview Findings

The sixth participant (P6), who is a senior, from the engineering consultancy firm was interviewed since he had expert knowledge of the smart lighting system in the case study. The participant was asked a set of questions relating to the current operational status of the smart lighting environment and FSA implemented. The findings from the interviews are reported on in this section.

Question 1: Does the current system provide real-time access to information?

In response to the first question P6 stated that "*Information is transferred from the smart light to the remote server every 2 minutes. The latency is set at the 2-minute time interval to reduce the data costs per SMS. The system makes use of an SMS based protocol. It is quite an inefficient mechanism of transferring data but as this project is still in its infancy we are looking for ways to* *improve".* P6 also stated that increasing the number of messages sent between the smart light and the server would result in higher data costs.

Question 2: Have you considered using an alternative communication protocol?

Asked if an alternative data protocol had been considered, the participant's response was that "*We implemented the ZigBee data transfer protocol during testing. However, as the smart lights are grid independent and are intended to be located at any facility without the use of wired communication is not feasible and we ZigBee because ZigBee is optimised for short-range and line-of-sight data transfer between two transmission points and the smart lights will not always be in the line-of-sight*". Furthermore it was established that the current system is not fully bi-directional that is full duplex. The control commands can only be sent with a response after the smart light initiate's communication with the remote server. Therefore, if a command to cut off inward current from the wind turbine due to an electric surge, the command can be executed anywhere between 1 second to 2 minutes depending on when last a request was sent by the client being the smart light.

Question 3: Does the system currently process the data recorded for issue diagnosis? If so what AI mechanisms have been implemented?

P^ stated that." *Currently we do not process any of the data recorded. The data recorded is simply logged onto a CSV file. In an instance that there is a fault we will look through the logged CSV data. In most instances the service technician has to get onsite to diagnose the problem. This has proved to be a problem as most smart lights are geographically dispersed*." P6 acknowledged the lack of data processing on the server side as a setback in the delivery of services. This means a service technician would not adequately diagnose a fault issue based on the data received. The participant P6 did, however, mention that smart lights can operate without human intervention. For example, in an event of a high surge in electricity from wind turbines, inbuilt functions would cut off supply from the generator to avoid damaging sensitive components on board the micro-controller. It was also established that there are no records kept of faults within the current system. The only information kept is the acknowledgement of the field service task performed as per job card for example repairs of maintenance on the system.

Three problems were identified from the interview conducted with P6 namely, lack of real-time access, high data transmission costs, half duplex communication protocol and inability to adequately diagnose faults. The communication protocol has a latency rate of 2 minutes, which in the context of the case study does not qualify as real-time as the participant acknowledged its inefficiency. An increase in the data transmission rate would result in an increase in communication costs as the protocol is an SMS based GSM protocol. The need to have low data transmission costs is essential in an IoT environment as smart objects and devices send large volumes of data (Section 3.6). The communication between the server and the client is half duplex that is data transmission is one directional at a time. It implies that the current system cannot handle communication from the smart light and the server at the same time. The current system does not also handle any data processing for issue diagnosis. Furthermore, when faults occur they are not recorded by the data logger. The fault report is recorded in a different system within the organisation in fulfilment of the job card requirements. Furthermore the researcher observed that technicians or engineers at the engineering consultancy firm do not make use of mobile technologies in the execution of field service tasks.

From the interview conducted it can be deduced that the smart lighting environment in the case study does not implement an FSA techniques and therefore the problems experienced within the case study do not all relate to the problems identified by literature and the interview findings with the field service experts. However, the case study does possess the features of an IoT ecosystem and there is a need for FSA to optimise FSM. Table 4-5 summaries the problems (CP1- to CP-6) identified within the case study in the smart lighting environment.

Table 4-5 Problems in the Smart Lighting Environment Case Study

Problem identified	Type	Participant
CP-1/PB5: Lack of real-time data transfer	Technical	P6
CP-2: High data transmission costs	Technical	P6
CP-3: Communication protocol half duplex	Technical	P6
CP-4: Inability to diagnose problems remotely due to the lack of data processing	Technical	P6
CP-5/PB4 Lack of integration with enterprise systems	Technical	P6
CP-6/PB13 Inadequate use of mobile technologies	Technical	Researcher observation

With the aid of IoT techniques and features, the maintenance of the lighting system can be optimised. The LED smart light has the computational capabilities to not only diagnose a problem when it occurs but also initiate communication with relevant parties to readily rectify it with minimal downtime. The use of IoT-enabled communication protocols can reduce the latency time and reduce data exchange costs. The underlying principles of IoT were used in the design and development of a FSA model to optimise after sales field service delivery. The objectives of the model and its structure are presented in the next section.

4.5. Objectives of an IoT Model for FSA

A prescriptive model aims at providing a possible solution to current or future problems within a practice. The proposed theoretical model shall describe a plausible solution that addresses some of the problems that have been identified within the practice of field service automation through the literature study (Section 3.2) and results gathered from interviews conducted with industrial stakeholders (Section 4.2). The objectives of the model are to:

- Classify the elements to be found within the FSA ecosystem.
- Provide patterns for the implementation of the data communication protocols within the ecosystem and how they interact.
- Facilitate integration between FSA and IoT in order for the FSA ecosystem to inherit benefits of an IoT ecosystem. Furthermore, it will provide additional information that identifies levels of IoT and establish a common terminology.
- Identify specific processes to be optimised in order to deliver high levels of efficiency within the ecosystem.
- Provide servitisation to field service organisations.
- Provide a distributed architecture.
- Provide a description of how the tasks at each level should be executed in order to maintain simplicity and allow for high scalability.
- Provide a foundation for FSA systems that possess high modularity capabilities.

Servitisation was proposed by Vandermerwe and Rada (1988) as they emphasised the concept of customer focus; combining products, services, support, and knowledge are the most important elements. They also stated that not only service industries but also manufacturing industries should focus on innovative value added service development in order to quickly enhance their core competencies. Servitisation is defined as the strategic innovation of an organisation's capabilities and processes to shift from selling products, to selling an integrated product and service offering that delivers value in use, that is. a Product-Service System (Vandermerwe & Rada 1988).

The elements within the model are not geographically restricted nor is their scope. That is, elements within the FSA theoretical model are not restricted in terms of locality nor scope.

For instance, sensors can reside within a single smart object and collect data about it or they can be spread across a wide network of objects which are sparsely distributed and a WSN can be used

4.6. System Requirements for an IoT-based FSA System

The system requirements for FSA were obtained from the findings of the DSRM activities. Each requirement is aimed at addressing either a problem identified or one of the KPIs listed (Section 3.4). The system requirements are listed in Table 4-6.

The access to device or equipment information is cardinal for field service providers to offer enhanced service delivery. As identified through the analysis of existing systems there is a lack of direct access to information from the OEMs that allows interfacing between a remote server and the device. However, as devices get smarter and the emergence of CPS systems and IoT this challenge is addressed. CPS systems and IoT will allow service providers to directly access information from OEM devices. Therefore, the model should be designed to allow for the ability to interface with OEM's equipment to access data. With the ability to interface with devices optimised, the cost of data exchange comes into question.

As stated by the senior engineer (Section 4.4.3) during the interview the cost of data transfer is a barrier in gaining real-time access to information. In order to address this concern data exchange protocols that are optimised for the low cost of data and its exchange should be used. RTC allows service technicians to interface not only with the devices but also with the administrative staff at the head office. Network communication protocols should also allow for remote procedural call mechanisms that will enable service technicians to remotely send actuation commands and controls to the devices.

FSA systems which make use of mobile technologies as a means of communication with service technicians have been identified as leading systems in the FSM sector. Therefore, support for interfacing with mobile technologies is a requirement for a FSA system. Furthermore, leading FSA systems make use of AI mechanisms in the execution of field service tasks such as scheduling (Section 3.11.5).

Standardisation has led to the successful implementation of the Smart factory project (Weyer et al., 2015). The standardisation of protocols, tasks and processes have enabled a multi-vendor technology ecosystem. Standardisation has been identified as one of the challenges of the successful growth of IoT (Section 3.8). The IoT-based FSA model will provide a basis for standardisation. Furthermore, the model shall also adopt security measures as outlined in Green's (2014) reference model. The system requirements used and the source, as well as the challenges and KPIs that are to be addressed, are summarised in Table 4-6.

Table 4-6 FSA System Requirements (Authors Own Construct)

No.	Requirements	Problem/KPI to be addressed	Source
FSA Problems			
R1	Provide support to facilitate the data accessibility between an OEM's device/equipment and a remote service provider	Inability to access information from devices causing inability to have holist view of system by service providers (PB 4,PB 8)	Literature /Interviews
R2	Provide low cost and secure data exchange protocol	High cost data transmission (PB14)	Interviews
R3	Use of intelligent algorithms for data analysis and task management	Inadequate automation of data analysis	Literature /Interviews
R4	Provide the support to enable ability to interface with mobile technologies	Inadequate use of mobile technologies(PB13)	Literature /KPIs/Interviews
R5	Allow for RTC	Inability to access information in real-time (PB5)	Interviews/Literature
R6	Provide support for RPC and controls capabilities	Inadequate bi-directional communication to actuate devices (PB 5)	Literature
R7	Facilitate the integration of CPS system principles	Inadequate environmental sensing capabilities	Literature
IoT Challenge			
R8	Provide support for security implementation at every level of interaction	IoT challenge	Literature
R9	Provide a platform for standardisation of protocols, tasks and procedures	IoT challenge	Literature /KPIs

Upon determining the objective and system requirements of an IoT-based FSA system the theoretical model was designed. The model shall be discussed in the next section.

4.7. An IoT Model for FSA

The model design and its components shall be discussed in this section. The model design was based on the objectives and systems requirements derived from research methods undertaken in this research thus far that is literature review, interviews and systems analysis.

4.7.1. Model Design

A model is an abstract representation of reality, useful for its explanatory, prescriptive and predictive power (Section 2.3.5). A prescriptive model is aimed at facilitating the design of a solution to a problem within a practice. Examples of prescriptive models are:

- The architecture design of a building; and
- Principles and goals of a conceptual model.

The proposed model for the optimisation of FSA using an IoT (Figure 3-13) applies a combination of elements from the three views of IoT. The model consists of:

- The Four Layered Architecture;
- The Three Phase Data Flow Process; and
- Definition and descriptions of IoT-based functions, techniques and patterns based on Green's IoT Seven Level Reference Model.

The model leverages the benefits of the three views of IoT to provide a standardised comprehensive model (Figure 3-13). The model utilises the structure of the Four Layered Architecture to describe its architecture and the components within it (Section 3.9.2). The Three Phase data flow process describes the interaction of the various components within the model (Section3.9.1). The functions, techniques and patterns implemented within the model are inherited from Green's (2014) IoT Seven Level Reference model (Section 3.9.3). Figure 4-8 illustrates the components from the three views that were used in the design of the proposed model.

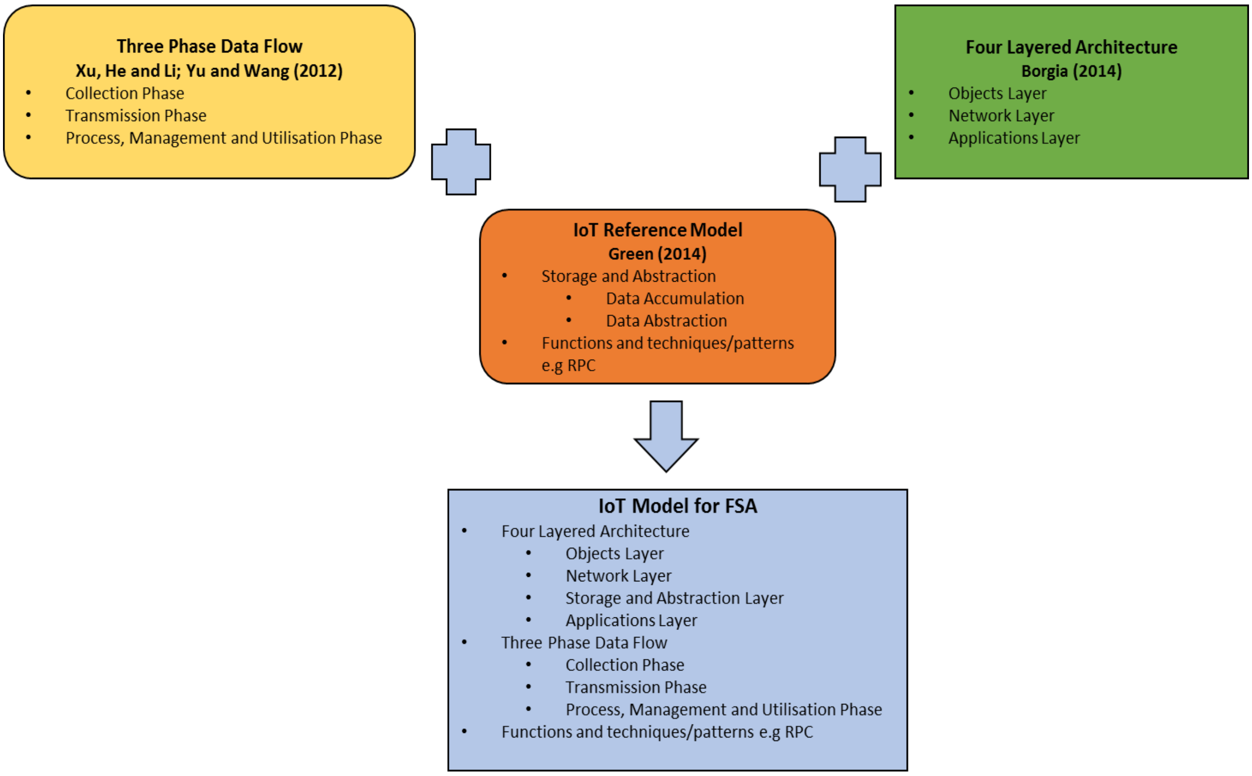

Figure 4-9 Combination of Elements from Three Views of an IoT

The model adopts its architecture from the Four Layered Architecture view and also adopts three of the four layer's naming conventions that is the Applications, Network and Objects Layer. However during the design of the model the researcher was of the opinion that Green's (2014) IoT Reference Models level four, Data Accumulation also referred as Data Storage, and five, Data Abstraction define the role of the data storage and abstraction layer. Therefore the Data Storage and Abstraction layer replaces the Services Layer in the Four Layered Architecture presented by Yu and Wang (2012) because the role of the layer is not only to provide services relating to storage but also abstraction mechanisms. The Three Phase Data Flow Process describe the three data processes as data moves from the Objects Layer to the Applications Layer. The next sections provide descriptions of the elements of the model.

4.7.2. Four Layered Architecture of Model

The proposed IoT model for FSA consists of four layers based on the four layers of the layered view architecture proposed by several researchers (Section 3.9.2), namely:

- The Objects Layer;
- The Network Layer;
- The Storage and Abstraction Layer; and

- The Applications Layer.

Figure 4-10 presents the model and its various layers and components. The Objects Layer contains the smart objects and other elements that bridge the gap between the cyber and the physical environments (Section 3.5.2). The Network Layer contains networking protocols and technologies that enable the transfer of data between the Objects Layer and the storage and abstraction layers (Section 3.9.3). Storage and abstraction processes along with data analysis process are found within the storage and abstraction layer. This layer contains cloud-computing and AI technologies and algorithms respectively. The Applications Layer consists of users and user-facing technologies. Services offered by the model are defined and consumed within the application layer. Within each layer are technologies that have been identified as enabling technologies for IoT (Section 3.7) and necessary for FSA (Section 3.4). Examples of these technologies include cloud-computing, mobile technologies and AI.

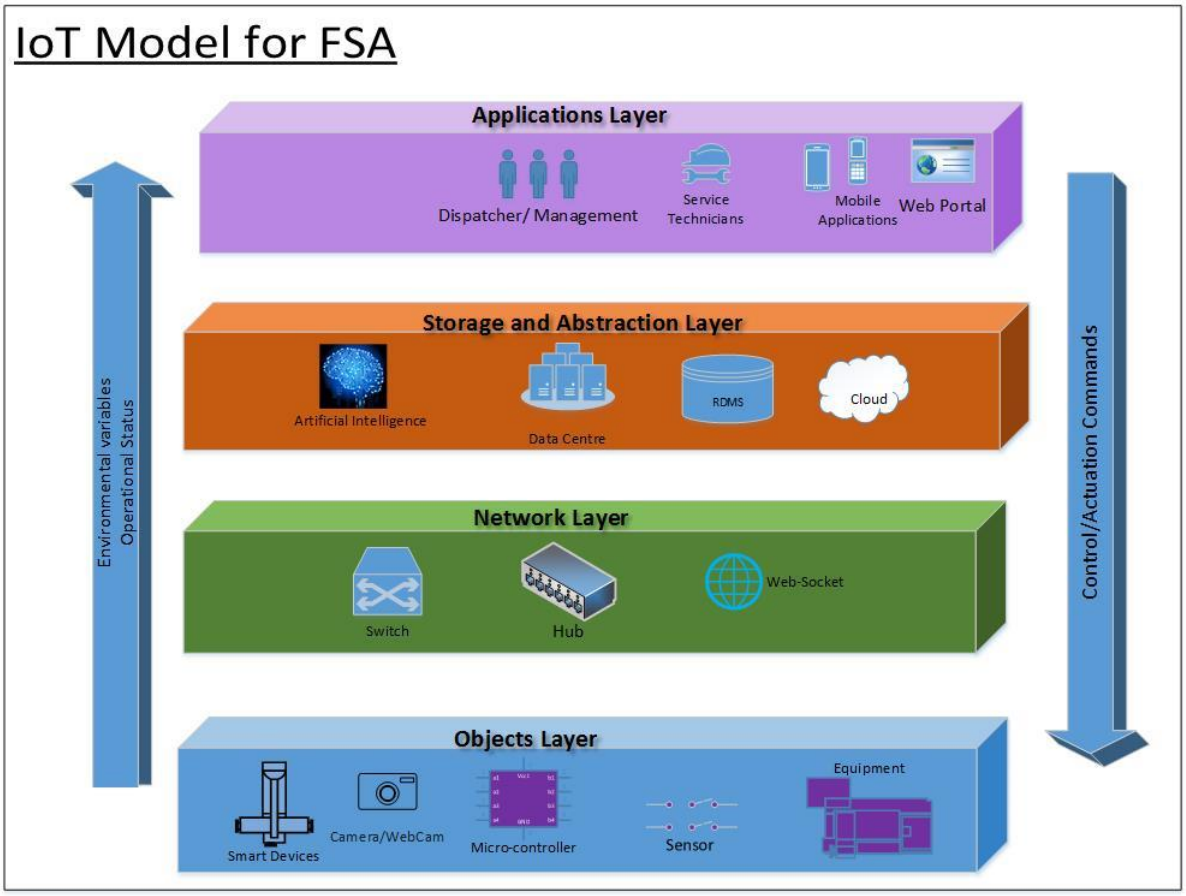

Figure 4-10 IoT Model for FSA (Authors Own Construct)

In an IoT ecosystem just like an automated field service system, there are multiple devices that generate and process data that is transmitted to different locations. The data is then consumed and acted upon by multiple applications to meet the needs of relevant stakeholders. The proposed prescriptive model (Section 2.3.5) purposes present components and their functions within the FSA ecosystem.

The four layers of the layered architecture of the model is presented. The Objects Layer is the first layer of the architecture. It is then followed by the Network Layer. The Network Layer precedes the data storage and abstraction layer which is the third layer of the model. The application layer is the fourth and topmost layer. The layered architecture shall be used to highlight the different elements of the model and how they interact. The flow of data across the various elements within the model shall be discussed by means of a data-flow architecture.

4.7.2.1. The Objects Layer

The object layer is the foundation layer of the Four Layered Architecture. It is the interface between the cyber and the physical world. The Objects Layer contains the smart objects which interact with the physical environment they are placed in. It consists of the smarts objects hardware made up of the sensors, actuators and embedded communication hardware. The components within the Objects Layer consists of:

- Smart objects/devices for example equipment (Section 3.9.2);
- Sensory technology (Section 3.9.2);
- Identification technology, that is, RFID, NFC tags (Section 3.9.2);
- Controlling/actuation devices for example Micro-controllers (Section 3.9.2); and
- Integrated monitoring devices for example camera's (Section 3.9.2).

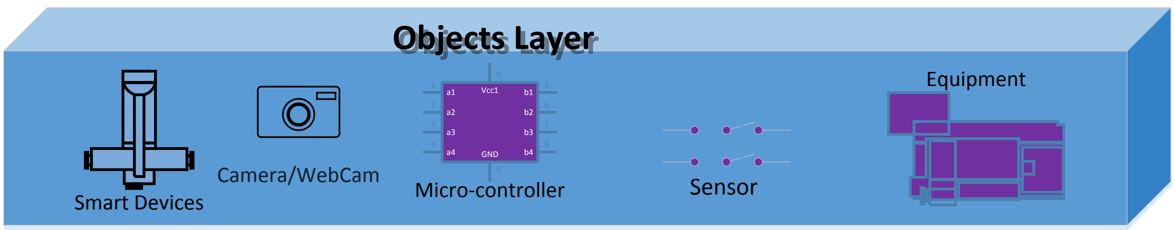

Figure 4-11 Objects Layer (Authors Own Construct)

Descriptions of the core characteristics of a smart object within the FSA domain are also provided within this layer. Each smart object within the Objects Layer should adhere to the basic characteristics (Section 3.9.2), namely:

- Being identifiable (should have a unique identifier);
- Ability to sense (have sensors); and
- Have computational and communication capabilities.

Objects identification and addressing

An object's identification needs to be externally accessible and also accessible over a network, which is the Internet (Section 3.7.1). An object's identification can be externally accessible by means of RFID tags or NFC tags. External accessibility enables the object to be identifiable by relevant stakeholders using readers. In the context of FSA, this is the first step toward the automation of the identification process of equipment to be serviced. In an environment which contains a high number of similar type of objects, such as a 300 hector solar farm, the automation of the objects identification process is cardinal in carrying out routine maintenance. The RFID or NFC tags will possess additional information apart from the ID of the object such as the last service date, date of installation and manufacture ID. All the information contained on the tag should be referenced back to a remote data repository ideally a database. The data repository resides within the third layer of the architecture and shall be discussed in the forthcoming section. An estimated 50 billion devices and smart objects will be online by the year 2020 (Section 3.6) the need to uniquely identify and manage each object individual is of at most importance. Each object should be uniquely identifiable in order for it to interact and communicate with other objects as well as other elements within the FSA ecosystem and the Internet as a whole.

The identification of an object, just like the identification of an individual, needs to be unique in order for the individual or object to be distinguished from other people or objects on the Internet. The importance of unique usernames within the information systems space is essential in not only ensuring that each user of a particular system can be distinguished from other users but also for security integrity of the users' information (Section 3.9.3). These are common properties that should also be implemented within objects as they become active entities on the Internet that share information with not only other objects but other systems. Each object is individually addressable so that it can be interconnected and accessed through the standards of the Internet. With the IPv6 looming on the horizon it will allow for devices to have unique IP addresses which may act as each devices unique identification (Section 3.7.3). This is made possible due to IPv6's addressing which makes use of 128 bits, unlike IPv4 which uses 32 bits (Section 3.7.3). Therefore, the unique IP address of an object under IPv6 should act as the device's unique identifier.

However, with IPv6 not yet fully implemented objects in the current context can still possess unique identification codes.

In the current Internet age IPv4 is still the most widely used Internet protocol, therefore the use of a unique IP address being mapped to objects unique identification is not a feasible solution as they are limited addresses available (Castro et al., 2013). To overcome this each object within the model, possess a unique identification (ID) which is not related to the IP address of that object. The ID to be assigned to an object should be uniquely identifiable globally, that is, an identifier that can guarantee uniqueness across space and time. In order to achieve this, the researcher proposes the use of a Globally Unique Identifier (GUID). GUID is a 128-bit integer number used to uniquely identify resources. An ID generated by GUID algorithms is unique enough that if 1,000,000 GUIDs per second were generated for a year the probability of a duplicate would only be 50%. IDs generated by GUIDs are used to track users in non-secure areas of the Internet due to their uniqueness. GUIDs are used by web servers to identify users in unsecure areas on the Internet and by the Windows operating system registry to identify COM DLLs. Apart from having the ID providing identification on the Internet, the object needs to be identifiable in the physical environment it is based. The ID used to identify an object within the cyber world of the Internet should be the same one used to provide the object with identity in the physical world thereby creating a link between the cyber and the physical worlds (Section 3.5.2). The ID in the physical world is important for a service technician to uniquely identify an object within its environment when he/she gets on site.

Objects sensing and control

The smart objects have sensors and actuators. The type of sensors that a smart object contains will be dependent on the object type. Ambient, temperature, current, voltage, motion and speed sensors are the sensors contained within each smart light. The data collected by the sensors is pre-processed by a microcontroller. It further offers local processing and storage capabilities to provide offline services and if required real-time control actuation of elements of the smart light such as cutting current from the battery pack to the LED light. The microcontroller translates the commands that are sent for actuation into machine readable instructions such as cutting current from the battery pack to the LED light within a smart light object. WSNs can be used in an environment where there is a network of sensors. WSN can be used to sense environmental variables such as temperature and humidity over a large area network.

Computational and communication Capability

Objects within the model ecosystem should possess the ability to transfer data and receive commands from remote locations. However as not all devices within the field services are IP enabled IoT, therefore communication gateways can be introduced. An IoT gateway is a device that aggregates sensor data, processes the sensor data before sending it through the Network Layer and translates between sensor protocols (Gubbi et al., 2013). It further offers local processing and storage capabilities to provide offline services and if required. The gateway can take the form of a micro-controller such as the Intel Gateway or a microcomputer such as a Raspberry Pii.

Table 4-7 Objects Characteristics and Hardware

Characteristic	Hardware and Technology
Objects Identification and addressing	RFID Tags NFC tags IPv6
Objects sensing and control	Individual Sensors WSN Motors Actuators
Computational and communication Capability	Micro-controller Raspberry Pii IoT Gateway

4.7.2.2. The Network Layer

The Network Layer defines the communication protocols and technologies by which data is transmitted from the Objects Layer to the data accumulation and abstraction layer. The components within the Network Layer consists of:

- Network communication technologies such as WAN, mobile telecommunication networks, Wi-Fi and wired technologies such as Ethernet (Section 3.7.3);
- Network technology hardware such as switches and hubs (Section 3.9.3); and
- Data communication protocols such as HTTP and web-sockets (Section 3.9.3).

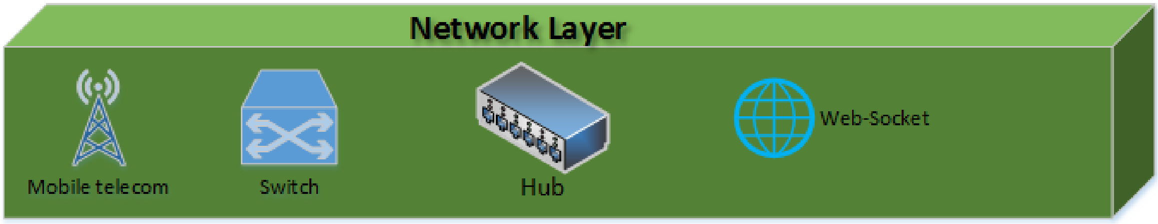

Figure 4-12 Network Layer

The Network Layer should allow for transmission of actuation commands and for a bi-directional fully duplex communication protocol that ensures efficient transfer of data packets (Huang, 2013). Huang (2013) proposes the use of Remote Procedural Call and Publish/Subscribe communication patterns to provide the IoT with Network Layer with actuation and bi-directional communication protocols. The RPC pattern is used for sending commands and controlling configurations of IoT devices. Whilst the Publish/Subscribe pattern is used for the efficient transferring of data within IoT applications.

RPC is one of the inter-process communication methods for data exchange among threads or processes on different hosts (Section 3.9.3). Unlike a local application case, where the code runs all locally, RPC solves the problem of executing codes across a distributed system over private networks or the Internet. RPC makes use of a message pattern protocol that includes two roles, client and server. Usually, the RPC message pattern is initiated by a client, which sends a request to a remote server.

From the perspective of an IoT the RPC pattern addresses one of the two most important interactions in the IoT application architecture, that is., sending commands or configuration control (Huang, 2013). In the case study, smart lights are in different locations from cities to rural locations. Commanding is helpful to configure a smart light remotely, for example setting the parameters such as device identification, timeout and reporting rate. As for an actuator the RPC pattern can control its action for example a light actuator also called a light switch has the actions of on and off. With commanding, the light can, thus, be switched on or off remotely. The server sends the command, then the smart light responds with a confirmation response of the command request. The response can be either a successful execution or an unsuccessful one. An example of RPC pattern is shown in Figure 4-13

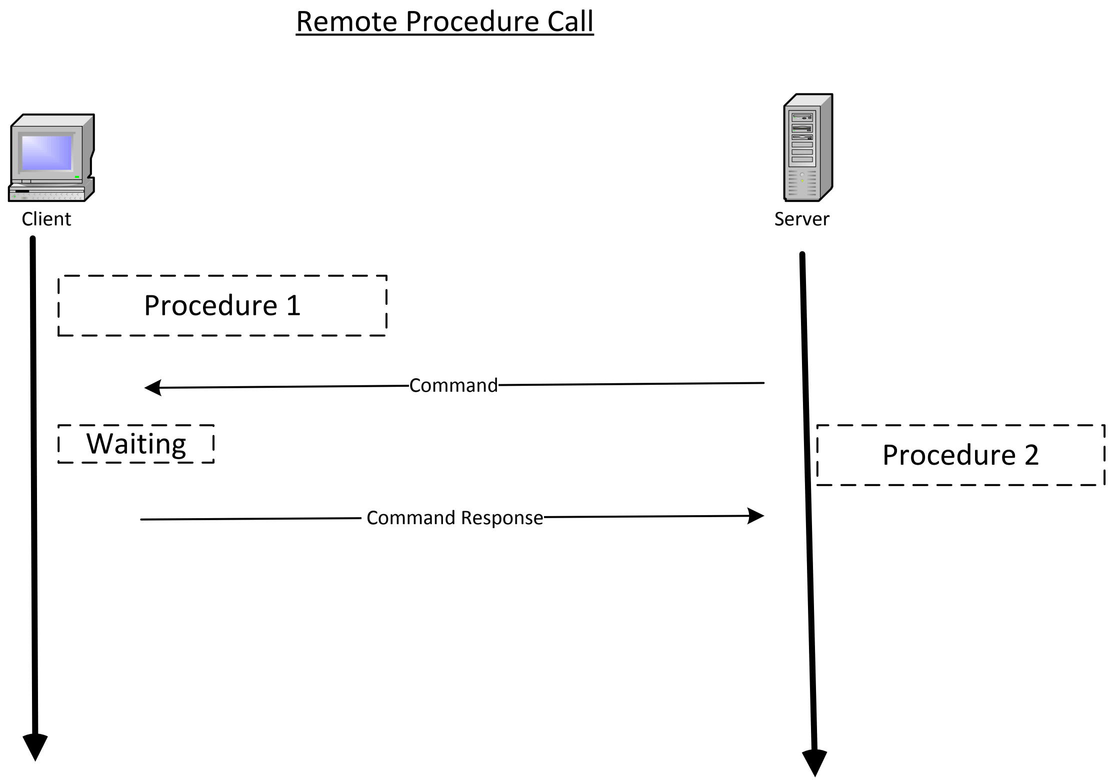

Figure 4-13 Remote Procedure Call

Publish/Subscribe (Pub/Sub) is a message exchange pattern where messages are exchanged by means of publishing and subscribing. A receiver/subscriber of a message is referred to as a subscriber and a sender of a message is referred to as a publisher. In most instances, each message contains a topic. A receiver filters and receives a message by the message topic. A receiver subscribes to a particular topic. Pub/Sub architecture consists, usually, at least publishers, subscribers and a broker(s). The broker facilitates the exchange of messages by mapping the right messages to the right receivers and exchanges messages among publishers and subscribers. It is worth noting that the publisher and the subscriber have the same characteristics. Therefore, a publisher can also be a subscriber and receives messages from other publishers; while a subscriber can also be a publisher and publishes messages with topics. Furthermore, messages exchanged between a publisher and a subscriber can occur simultaneously and there is no rule that states that in order for a topic to be published there should be subscribers. For instance, a publisher can publish a message to a topic without subscribing any topic; or even no one subscribes the topic. The subscriber does not have to subscribe any topic either. All the message exchanging logics, however, are handled by the broker(s). The broker(s) specifies and implements corresponding functions to different messaging situations.

The concept of the Pub/Sub pattern is ideal for FSA. Pub/Sub enables the ability for bi-directional full duplex interaction between two devices within the FSA ecosystem. Data can be exchanged horizontally from one object to another or vertically from the Objects Layer to the abstraction and aggregation layer and vice versa. For example, object A collects temperature data and humidity data. Object A then submits the collected data to the other object or data centre for the purpose of verifying environmental conditions or for monitoring respectively. One strategy, which organises and manages the data sent by Object A, is to set the topic of each message to the data type for example “t-h” for temperature and humidity. Subsequently, Object B or the data centre can easily categorise the data for further processing.

Through the implementation of the RPC procedure and Pub/Sub message pattern, the issue of inadequate bi-directional communication for actuation and data transfer is addressed (Table 4-6). A standard protocol procedure is also identified through the implementation of RPC and Pub/Sub procedures within the Network Layer.

4.7.2.3. Data Storage and Abstraction Layer

The data storage and abstraction layer deals with the storage, processing and analysing of data. In this layer, the data in motion from the Network Layer is converted to data at rest. Data at rest can be stored either in a file system or relational database or a big data system (NoSQL) or cloud-computing data repository (Section 3.5.1). Data processing can be performed by AI algorithms or systems (Section 3.7.5). Therefore, the components within this layer consist of:

- Intelligent systems such as AI; (Section 3.7.5); and
- Data storage and abstraction technologies such as cloud-computing and data centres. (Section 3.5.1).

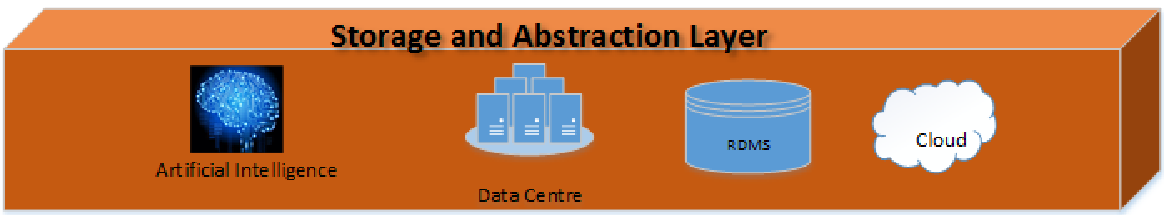

Figure 4-14 Data Storage and Abstraction Layer

The data is to be processed before being put at rest to establish the following:

- The priority level of the data. Data of high priority shall be processed by relevant intelligent algorithms. For example, if the temperature reading captured is above the acceptable threshold a flag need be triggered to allow for fault analysis processing.
- Data storage type required and its preservation: The type of data storage type required will be determined by the intended use that is if the data should be kept on a disk in a non-volatile state or accumulated in memory for short term use.
- The need for data computation: The data should be combined, recomputed, or aggregated with previously stored information.

Once the data has been put to rest it can be used by the application when necessary. Data abstraction functions are implemented at this level to aid the rendering of data and its storage in order to enable performance-enhanced applications. The data abstraction functions should reconcile multiple data formats from the different data sources as well as ensure the data is complete when sent to an application in the application layer (Section 3.9.2). The abstraction enables data protection through appropriate authentication and researcherisation techniques. The consistent semantics of data across the different data sources is also managed by data abstraction functions. Once abstracted data is forwarded to the application layer and is consumed by services and applications as well as providing feedback to control devices in the Objects Layer.

AI mechanisms can be used for the analysis of data in order to model natural intelligence and solve complex problems. Through the use of AI mechanisms such as decision trees expert analysis can be used for deductive reasoning when equipment failure arises (Section 3.7.5). AI mechanisms can also be used in the efficient completion of complex tasks and problems. For instance with the use of artificial neural networks the scheduling and dispatching of field service technicians can be optimised (Table 3-8).

4.7.2.4. Applications Layer

The Applications Layer contains services and applications that consume data from the data Storage and Abstraction layer. The Applications Layer includes applications that are focused on monitoring and controlling devices within the Objects Layer by means of the data retrieved from the data storage and abstraction layer. Monitoring and control applications represent many different application models, programming patterns, and software stacks, leading to discussions of operating systems, mobility, application servers, and multi-threading (Section 3.9.2). The complexity of the applications vary widely. Monitoring and controlling applications enable users such as dispatchers and managements to visualise the operational status of equipment from a remote location. The visualisation of the devices can be done through web-portals, desktop and mobile applications (Figure 4-15). The wide range of monitoring platforms to be used is made possible through the data abstraction performed within the abstraction layer. The data abstraction enables the transfer of data to different platforms customised to the platforms needs. Actuation commands can be initiated by users through the controlling applications. The actuation commands are sent via RPC requests. Therefore, applications within this layer may be used to manage various devices in the Objects Layer. Enterprise systems such as ERPs can be used to enhance operational efficiency.

ERP systems may integrate a field service organisation's business processes and all information that is relevant to manage service delivery .This integration streamlines information flow and results in benefits in value chain optimisation such as reduced inventory costs, process improvements, and improved customer service. The information generated by the ERP systems can be used to make strategic and operational decisions. Integration of applications can also be extended to mobile applications which can be used by service technicians to get job cards, geographical locations of client sites and also monitor the operational status of the equipment. The need for integration of mobile technologies into FSA platforms was identified both in the systems analysis and the interviews conducted.

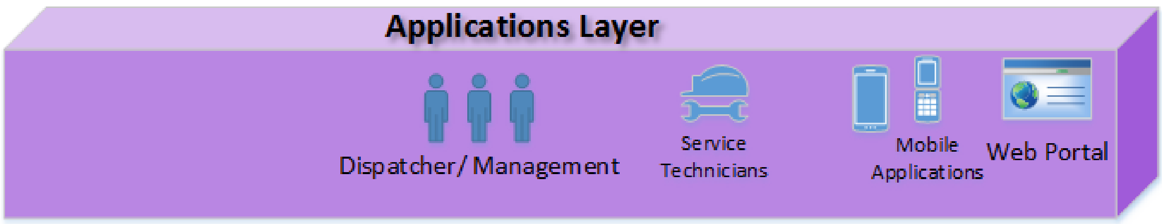

Figure 4-15 Applications Layer

4.7.3. Three Phase Data Flow Process

The data within the proposed IoT Model for FSA is generated from the Objects Layer and utilised in the Applications Layer. The Three Phase Data Flow Process adapted from Borgia's (2014) IoT architecture (Figure 3-10) is used to illustrate the flow of data within the FSA ecosystem (Figure 4-16). Data is generated and collected by devices within the Objects Layer. The data collected contains parameters describing the current operational conditions of the object or the environmental it resides in. Once the data has been collected it is then transmitted over network transmission protocols and communication technologies (Section 4.7.3.2). The data is then processed and utilised by relevant stakeholders or applications (Section 4.7.3.3). The processing and utilisation phase entails the use of various data processing techniques such as data mining, data visualisation, and data forecasting in order to generate information to be used for multiple services such as field services automation. Figure 4-16 illustrates an overview of the detailed flow of data in the Three Phase Data Flow Process of the model, which shall be discussed in more detail in the forthcoming paragraphs.

The three phases of data flow as proposed by Borgia (2014) and adopted in the model are as follows:

- The collection phase (Section 3.9.1);
- The transmission phase (Section 3.9.1); and
- The processing, managing and utilisation phase. (Section 3.9.1).

The three phases of the data flow architecture shall be used to discuss the seamless interaction amongst the components within the model (Figure 3-10).

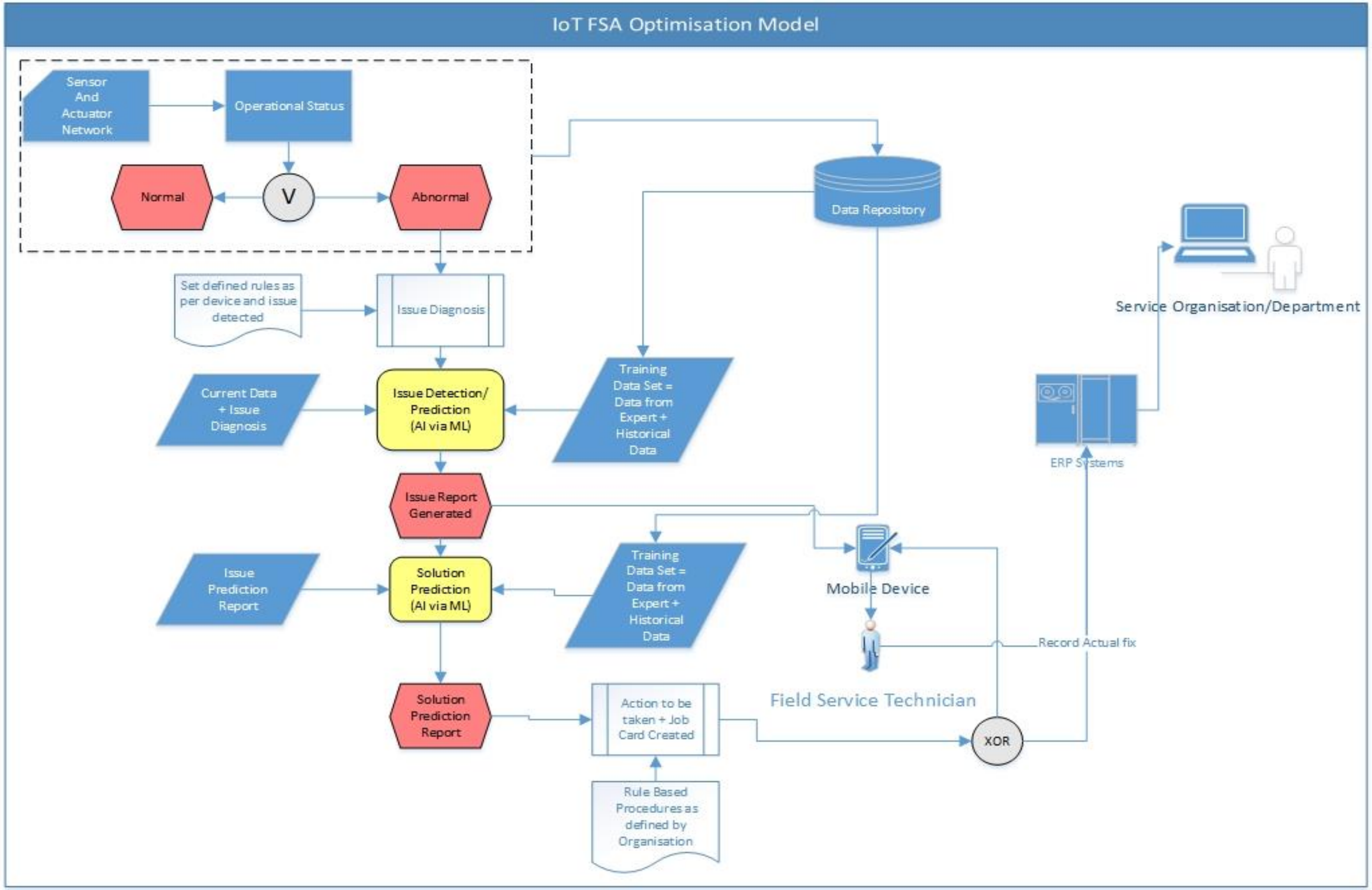

Figure 4-16 Three Phase Data Flow Process Overview

4.7.3.1. Collection Phase

Data is collected by the sensors and is then pre-processed by a gateway which monitors the operational status of the machine. The gateway determines if the operational status is normal or abnormal. The parameters that determine the operational status of categorisation are predefined conditions that can be set by object operators or manufacturers. For example, the current from an energy source, such as a wind turbine or solar panel, is considered normal if it is between 0.5 - 2 Amps. If the flow of current is above 2 Amps that would be considered as an abnormal state which could damage equipment on the battery management systems circuit board and would trigger a preventative action to protect fragile components within the battery management systems circuit board (Figure 4-17).

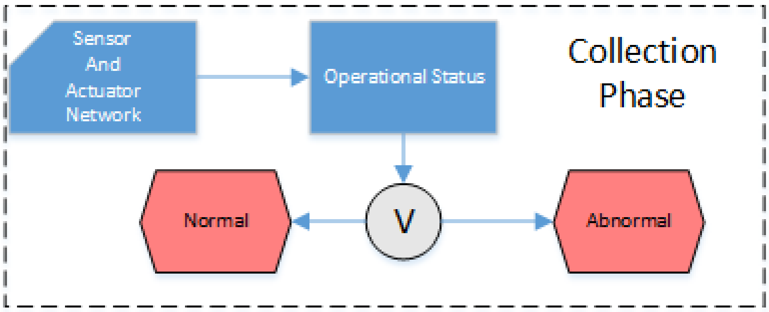

Figure 4-17 Collection Phase

4.7.3.2. Transmission Phase

The transmission phase, transmits data from the data collection phase to the processing, managing and utilisation phase. As smart objects will be required to transmit data in real-time and should allow actuation command transmission, the network should be bidirectional and enable RTC. The transmission phase should handle different types of data transportation formats such as XML, JSON and other formats available. In network environments where data transmission costs are not an issue the format in which data is interchanged is not a concern protocols based on SOAP or XML can be utilised. In the case of smart objects using standards such as GPRS, each byte that needs to be transferred comes with a cost via the mobile network. An alternative form of a communication protocol which restricts the volume of data should be considered such as JSON over web-sockets.

4.7.3.3. Processing, Managing and Utilisation Phase

Once data has been collected from the various smart objects it is processed and utilised by various applications. The processing of data for specific means in the layered architecture context occurs in the application layer. Data processing can occur on static data or streaming data depending on the required usage for the data. For this reason, the processing, managing and utilisation phase contains techniques for data processing that cater for both static and streaming data types. Stream computing techniques can be used in the analysis and processing of streaming data.

In the context of FSA streaming computing used to process the streaming data that is generated continuously by the thousands of data sources that are simultaneously sending data. The streaming data generated within field services include log files generated by smart objects such as equipment service usage data from smart meters. Stream processing, unlike batch processing, requires the ingestion of sequences of data, and the incremental updating of metrics, reports, and summary statistics in response to each arriving data record. Streaming data is better suited for real-time monitoring and response functions. An example of a streaming data in FSA is where sensors in industrial equipment or transportation vehicles send data to a streaming application. The application monitors performance detects any potential defects in advance and places a spare part order automatically reducing the onsite time and preventing equipment downtime.

A streaming application can make use of machine learning techniques to enhance data processing. Machine learning techniques can be used in the processing of data for the purpose of equipment fault detection. Machine learning techniques include artificial neural networks, evolutionary computing or decision trees (Basu et al., 2014).

Figure 4-18 illustrates the movement of data through the processing, analysis, and utilisation phase. In the event that the operational status of a smart object is abnormal, the data logs undergo pre-processing. The pre-processing will be governed by a set of defined rules specific to a particular device. The pre-processing would ideally occur closer to the edge of the network within the FSA ecosystem. Once the data has been pre-processed into a format that is ideal for machine learning to be applied to it. During the first phase of the application of machine learning (ML), the exact cause of the equipment failure or malfunction is detected. This is based on a training set that compromises of an experts' opinion and historical data if any of the particular equipment. The historical data relates to previous fault reports which may possess similar characteristics as those detected from the pre-processing issue diagnosis.

An issue report is then generated which details the specific issue(s) identified. The issue report is sent to a service technician and to the second phase of ML. The service technician receives a notification of the equipment failure and the report of the issue causing its failure. During the second phase of the ML process, a plausible solution is determined. Similar to the first ML phase the solution prediction phase consists of ML techniques which have a training data set that is composed of an experts' opinion as well as historical data. The historical data is based on solutions provided for a similar kind of fault as per the issue report. Once an appropriate solution has been deduced a solution prediction report is then generated.

The solution report is then transferred to an 'Action to be taken Phase'. It is at this point that a job card is created based on the rule-based system of a specific field service organisation. The job card addresses the service technician to be consulted based on a field force automation software. This aspect is out of scope for this study (Section 1.7). Once the job card has been created it is saved within an ERP system or any other field service enterprise suite. Once a service technician has been on-site and addressed the fault reported. A final report stating the cause and the solution to the problem is stored in a data repository such as a data warehouse or a relational database.

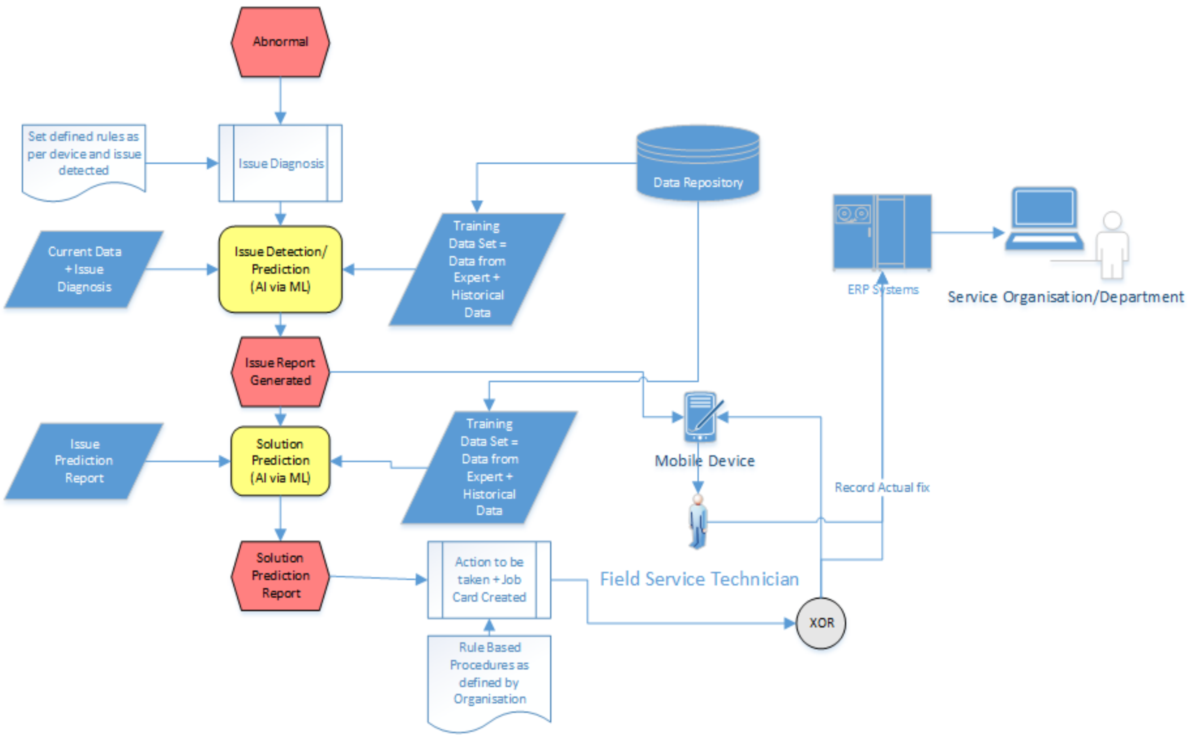

Figure 4-18 Data Processing, Managing and Utilisation Phase

4.8. Summary of Technologies and Techniques used in the IoT model for FSA

Figure 4-17 illustrates the comprehensive model consisting of the Four Layered Architecture, the Three Phase Data Flow Process and the components and functions within it. Several technologies and techniques were used in the design of the IoT Model for FSA (Section 4.7). The model consists of a Four Layered Architecture (Section 4.7.1), a Three Phase Data Flow Process (Section 4.7.2) and components and functions of the IoT.

The Four Layered Architecture describes the elements within each of the four layers of architecture. The Objects Layer contains data collection and data acquisition technologies. The data collection technologies within the Objects Layer include RFID, NFC and WSN (Table 4-7). Whilst the data acquisition technologies include temperature, humidity and voltage sensors (Section 4.7.1.1). The elements within the Objects Layer provide object identification, sensing and computation characteristics (Table 4-7). The Network Layer made use of the RPC and Publish/Subscribe patterns for fully duplex bi-directional communication protocols that enable the actuation command capabilities (Section 4.7.2). The Data Storage and Abstraction layer uses AI mechanisms for the processing and analysis of data. Cloud-computing and RDMS are data storage facilities suggested in this layer. The users of FSA applications such as dispatchers and service technicians consume services within the Applications Layer. The Applications Layer consists of SOA techniques such as the REST API protocols that enhance web service delivery and also make it easier to implement platform neutral applications.

The Three Phase Data Flow Process describes the flow of data from the collection phase to the processing, managing and utilisation phase. The collection phase occurs in the Objects Layer of the Four Layered Architecture. The collection phase reports on the event driven processes during the collection of the data. The transmission phase highlights the need of a low cost data exchange protocol for the transmission of data within the IoT model for FSA. The processing, managing and utilisation phase within the model highlights the role the AI techniques play in analysis of data to diagnose faults during downtime (Section 4.7.2.3).

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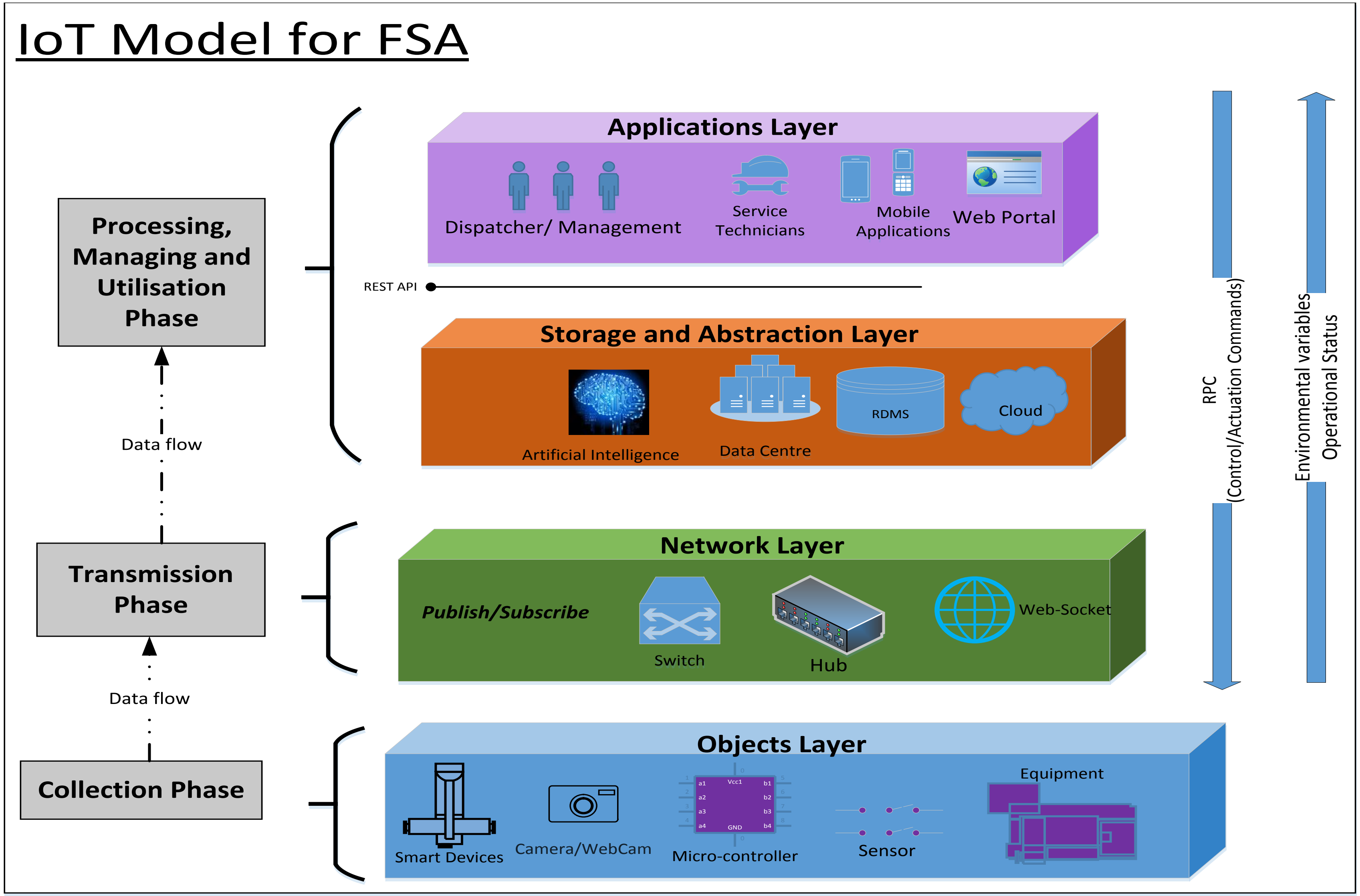

Figure 4-19 Comprehensive IoT Model for FSA

4.9. Conclusions

An objective of the relevance cycle in Hevner (2007) is to determine the requirements of an artefact by evaluating or investigating the practice. Through the interviews conducted with industry experts from FSM and smart lighting, the problems determined through the rigour cycle were confirmed. New problems were also identified such as the lack of a holistic view of field service delivery by service providers. The smart lighting environment possesses technology similarities with an IoT ecosystem such as the use of sensing data to optimise resource use and operational efficiency. These characteristics makes the smart lighting environment an ideal case study context for this research. An interview conducted with a senior engineer, at the case study engineering consultancy firm, highlighted some problems specific to the existing smart lighting system they developed for instance the lack of data analysis for fault diagnosis . These problems are a barrier to the execution of field service tasks such as repairs and maintenance.

The findings from the interviews conducted coupled with the literature study and existing systems analysis aided in the establishment of objectives for the design of the theoretical model and for the requirements of an IoT-based FSA system. The theoretical model proposed is a prescriptive artefact that can be used in the development of an FSA solution that can address the problems faced by FSM in the delivery of after-sales field services.

This chapter fulfilled the following research objectives, namely:

- *RO 4: Determine the real-world problems faced by field service organisations.*
- *RO 5: Identify the requirements and objectives of an IoT-based FSA system.*
- *RO 6: Design an IoT model to optimise FSA.*

By fulfilling these objectives three deliverables were provided. The deliverables are the system requirements of an IoT-based FSA system, the objectives of the IoT Model for FSA, the theoretical model as the artefact and the real-world problems identified through the interviews conducted. The next chapter shall discuss in detail the development of the KapCha prototype based on the system requirements of an IoT-based FSA system and the model.

Chapter 5. Development, Demonstration and Evaluation of Prototypes

5.1. Introduction

The previous chapter revealed the real-world problems of FSA through the interview findings, introduced the proposed IoT model for FSA and identified the requirements for a system for FSA. This chapter will report on the third and fourth activities of DSRM namely Development and Demonstration of the artefact (Figure 5-1).

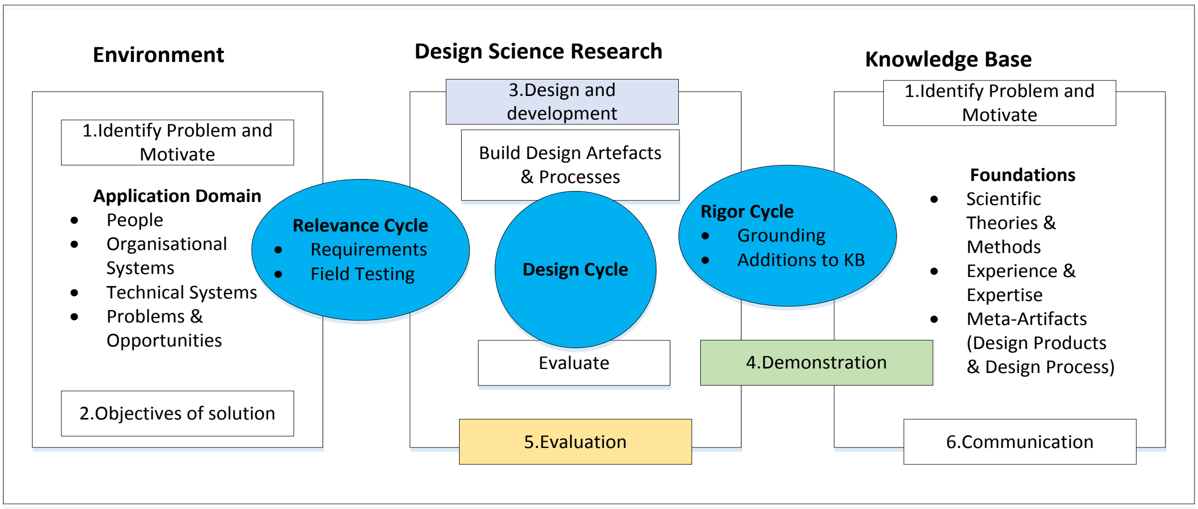

Figure 5-1 Chapter 5 Activities in Adapted DSRM

The development of the artefact, thereby addressing the sixth research question which is:

RQ 6. How can a FSA system be developed using the model?

Several evaluation strategies and methods suitable for DSRM are investigated (Section 5.2). The incremental prototyping approach is used in conjunction with the design cycles of DSRM (Section 5.3). The evaluation plan to be used in this study is outlined (Section 5.4). A proof of concept prototype shall be developed for the smart lighting case study in order to demonstrate the ability to implement a FSA system based on the proposed model (Section 5.5). Finally, conclusions will be drawn based on the findings of the chapter (Section 5.6).

5.2. Evaluation Strategies and Methods for DSR

Evaluation in DSR is concerned with the assessment of DSR outputs, including theory and artefacts. Hevner, March, Park and Ram (2004) identify evaluation as an important aspect of DSR that helps researchers to demonstrate the utility, quality, and efficacy of a design artefact using rigorous evaluation methods. It is vital that artefacts are evaluated in order to assess their impact on solving a problem within a real-world context. Pries-Heje et al. (2008) support acknowledge the importance of artefact evaluations by highlighting the impact evaluation has on the designer's thinking. The evaluations tend to influence the designer's thinking due to the iterative nature of build and evaluate within the design cycle. The design cycle seeks not to only deliver a well-defined artefact but also to contribute to the body of knowledge within the research domain. Pries-Heje et al. (2008) argue that without knowledge generation during evaluation, DSR may conclude with only theorising about the utility design of the artefact and therefore not fulfilling research goals affiliated with new knowledge generation by assessing the impact of the artefact within the practice. Therefore, the evaluation process not only addresses the quality of the artefact as a utility but also the quality of its knowledge output. The significance of the quality of knowledge output raises the need to have sound evaluation strategies and methods.

The Framework for Evaluation in Design Science Research (FEDs) was developed by Venable et al. (2014) for evaluation in DSR. The objective of the FEDS framework is to aid DSR researchers in establishing an appropriate evaluation strategy and evaluation methods to meet the needs of their particular DSR project (Figure 5-2). The FEDs framework addresses the question: What would be a good way to guide the design of an appropriate strategy for conducting the various evaluation activities needed throughout a DSR project?

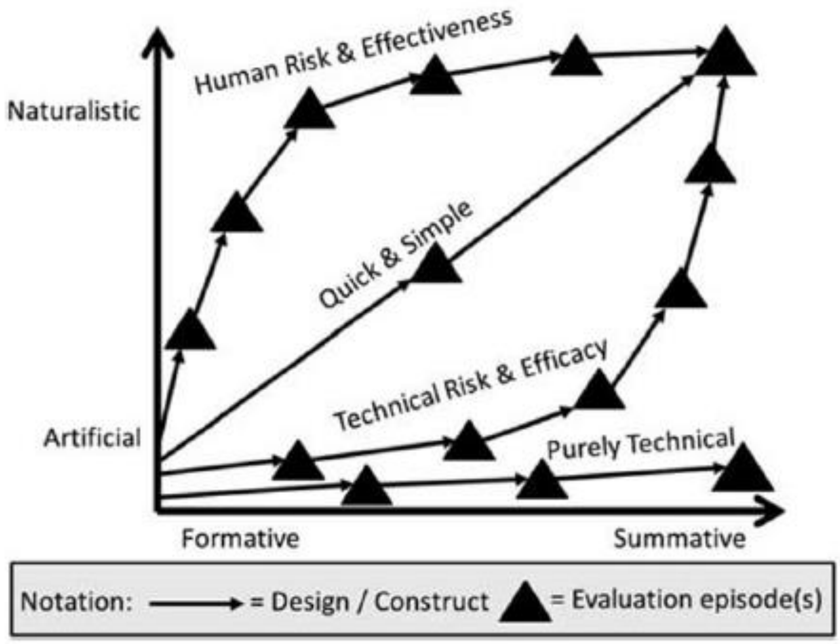

Figure 5-2 Framework for Evaluation in Design Science with Strategies (Venable et al., 2014)

The FEDS framework not only aids researchers in establishing the appropriate evaluation strategy or methods for the output of a DSR research project but also provides a process for using the framework to design the particular evaluation research strategy. The framework supports evaluation design research decisions by creating a bridge that maps evaluation goals to evaluation strategies. The FEDS framework is built on the basis of the following:

- The functional purpose of the evaluation; and
- The paradigm of the evaluation

5.2.1. Functional Purpose of Evaluation

Existing DSR literature classify evaluation methods according to the functional purpose of an evaluation (A. Hevner & Chatterjee, 2010; Pries-Heje et al., 2008; Venable et al., 2014). Venable et al. (2014) identify two categories of evaluation methods based on the functional purpose, namely:

- Formative evaluation; and
- Summative evaluation.

The two categories classify evaluations according to the question of *why an evaluation should be conducted* (Venable et al., 2014). Formative evaluations are used to produce empirically based interpretations that provide a basis for successful action in improving the characteristics or performance of the artefact. Formative evaluations focus on consequences and support the kinds of decisions that intend to improve the artefact. Summative evaluations are used to produce empirically based interpretations that provide a basis for creating shared meanings about the artefact in the face of different contexts. Summative evaluations focus on meanings and support the kinds of decisions that intend to influence the selection of the artefact for an application. Therefore, it can be deduced that formative evaluations can be performed during the design of the artefact through a design and evaluate approach making it suitable for the iterative nature of DSR. On the other hand, a summative evaluation can be performed to assess the performance of the utility within practice and knowledge generation. Table 5-1 provides a summary on the two categorises of evaluations.

Table 5-1 Functional Purpose of Evaluation

Why evaluate (Functional purpose)	
Formative evaluation	Help improve outcome of process/artefact under evaluation
Summative evaluation	Evaluate the extent that the outcomes match the expectations of the process/artefact.

5.2.2. Paradigm of Evaluations

The paradigm of evaluation refers to the methods of *how* to evaluate (Pries-Heje et al., 2008; Venable et al., 2014). The paradigm of evaluation is characterised as artificial or naturalistic. An artificial evaluation examines the performance of an artefact in a controlled and non-realistic way. It is unreal in some way based on three realities which are unreal users, unreal systems and unreal problems that are not held by the users or not real tasks (Sun and Kantor 2006). Artificial evaluation methods includes:

- Laboratory experiments;
- Field experiments;
- Simulations;
- Criteria-based analysis;

- Theoretical arguments ; and
- Mathematical proofs.

Naturalistic evaluation, on the other hand, explores the performance of a solution technology in its real environmental context of where it shall be used. Through the examination of the technology within the real environmental context, naturalistic evaluation encompasses all the complexities of human practice. Examples of naturalistic evaluation methods include:

- Case studies;
- Field studies;
- Surveys; and
- Hermeneutic methods.

5.2.3. FEDS Evaluation Strategies

The FEDS framework proposed by Venable et al. (2014) emphasise the need to establish an appropriate evaluation strategy and selection criteria of methods that best suit the needs of a particular research project. Four evaluation strategies are identified by the FEDS framework namely:

- Quick and simple;
- Human risk and effectiveness;
- Technical risk and efficacy; and
- Purely technical artefact.

The quick and simple strategy conducts a relatively little formative evaluation and progresses quickly to summative and more naturalistic evaluations. The evaluation trajectory of this strategy includes relatively few evaluation episodes (perhaps even only one summative evaluation at the end). Such a strategy is low cost and encourages quick project conclusion, but may not be reasonable in the face of various design risks (Venable et al., 2014). The human risk and effectiveness strategy emphasise formative evaluations early in the process, possibly with artificial-formative evaluations, but progressing quickly to more naturalistic-formative evaluations. Near the end of this strategy more summative evaluations are engaged, which focus on rigorous evaluation of the effectiveness of the artefact, that is, that the utility/benefits of the artefact will continue to accrue even when the artefact is placed in operation in real organisational situations and over the long run, despite the complications of human and social difficulties of adoption and use (Venable et al., 2014)..

The technical risk and efficacy strategy emphasise formative evaluations iteratively early in the process, but progressively moving towards summative artificial evaluations. Artificial-summative evaluations are used to rigorously determine the efficacy of the artefact, that is, that the utility/benefits derived from the use of the artefact are due to the artefact, not due to other factors. Near the end of this strategy more summative-naturalistic evaluations are engaged (Venable et al., 2014).

A fourth strategy, the purely technical strategy is used when an artefact is purely technical, without human users, or planned deployment with users is so far removed from what is developed to make naturalistic evaluation irrelevant. This strategy is similar to the quick and simple strategy, but favours artificial over naturalistic evaluations throughout the process, as naturalistic strategies are irrelevant to purely technical artefacts or when planned deployment with users is far in the future (Venable et al., 2014). Table 5-2 summarises the relevant circumstances when one might select each of the four strategies.

Table 5-2 Circumstances for Selecting a Relevant DSR Evaluation Strategy-Adapted from Venable et al. (2014)

DSR evaluation strategies	**Circumstance selection criteria**	**Functional Purpose**	**Paradigm Evaluations**
Quick and simple	If small and simple construction of design, with low social and technical risk and uncertainty	Formative Summative	Naturalistic
Human risk and effectiveness	If the major design risk is social or user oriented and/or If it is relatively cheap to evaluate with real users in their real context and/or If a critical goal of the evaluation is to rigorously establish that the utility/benefit will continue in real situations and over the long run	Formative Summative	Artificial- Naturalistic
Technical risk and efficacy	If the major design risk is technically oriented and/or If it is prohibitively expensive to evaluate with real users and real systems in the real setting and/or If a critical goal of the evaluation is to rigorously establish that the utility/benefit is due to the artefact, not something else	Formative Summative-	Artificial Naturalistic
Purely technical artefact	If artefact is purely technical (no social aspects) or artefact use will be well in future and not today		Artificial

5.3. Incremental Prototyping Approach and Design

A prototype is a basic working model of a product, typically built for demonstration, and forms part of the development methodology (Szekely, 1995). A basic version of the design artefact is built, tested, and then revised until it is deemed acceptable. Incremental prototyping is selected to iteratively build the practical artefact, named KapCha. Incremental prototyping is defined as the building of the design artefact by building individual prototypes (Guida, Lamperti, & Zanella, 2013). Towards the end of this process, these prototypes are merged into an overall design. There are several benefits of using incremental prototyping:

- The software component is generated quickly and early;
- Prototypes support the identifying and addressing issues at the initial stages;
- Ambiguity is eliminated by improving the understanding of the functional requirements of the design artefact;
- Prototyping ensures the design artefact does what it is supposed to – not what the developer thinks it ought to do; and
- It is easier to test and debug during a smaller iteration.

The evaluation plan to be applied in this research shall be discussed in the next section.

5.4. Evaluation Plan

The FEDS framework (Venable et al., 2014) will be adopted for the evaluation in this study. Upon the selection of a strategy, the FEDS framework provides a four-step process of executing the strategy. The four steps proposed in the FEDS framework and adopted in this study are:

- Establishing the objectives of the evaluation;
- Selecting the appropriate evaluation methods; and
- Designing the individual evaluation episodes.

The evaluation plan illustrates how the model as a theoretical artefact shall be evaluated and identifies the evaluation strategy and methods to be used during the evaluation process. The objectives of the evaluation process shall be discussed before the presentation of the evaluation process. The evaluation process shall involve the evaluation of the theoretical model and the evaluation of the implemented prototype.

5.4.1. Establishing the Evaluation Objectives

The primary objective of the evaluations in this study is to evaluate the artefacts, which are :

- The theoretical artefact (the IoT model for FSA) that consists of a:
  - Four Layered Architecture; and
  - Three Phase Data Flow Process.
- The practical artefact and real-world solution the KapCha prototype.

The IoT model for FSA was designed from literature, an extant system analysis and interviews to optimise the automation of a field service organisation's operations and to address the problems that organisations face with FSM (Table 4-4).

The KapCha prototype was developed as a proof of context to illustrate the ability to develop a system based on the model. The KapCha prototype is an implementation of an FSA smart lighting system in the case study. KapCha makes use of IoT techniques, technologies and processes in addressing the challenges of real-time access to information as well as the provision of accurate information to aid a field technician during downtime. The information provided is in form of a report generated using AI technics to establish what the probable cause of the downtime is in an attempt to minimise on-site time.

The objectives of the evaluations are:

- To evaluate the ability of the proposed model to meet the aim of optimising FSA
- To identify any potential problems with the design of the IoT model for FSA and the KapCha prototype.

The addressing of the aforementioned objectives fulfils the seventh research question which is:

> *RQ 7. How can the KapCha prototype optimise FSA within the smart lighting environment in the case study?*

5.4.2. Evaluation Design Process and Methods

The selection of the evaluation methods was based on mapping the evaluation objectives to the evaluation strategy selected, as recommended by Venable et al. (2014) summarised in Table 5-2. The evaluation strategy selected for this research was the technical risk and efficacy strategy, due to the technical nature of the IoT and the fact that it would be expensive to evaluate the artefacts completely with real users and systems. The technical risk and efficacy strategy focuses on formative iterative evaluation in the early process of design and development but progressively moves towards artificial-summative evaluations of the artefact. The technical risk and efficacy strategy is used in this study with a combination of methods and approaches in the evaluations (Figure 5 2) used to evaluate the model and the KapCha prototype.

The KapCha prototypes will be evaluated by means of:

- Iterative formative evaluations; and
- Summative evaluations (summative-naturalistic evaluations).

The IoT model for FSA will be evaluated by means of:

- Artificial-summative evaluation.

During the development of the KapCha prototype, iterative formative evaluations will be conducted to evaluate components of the KapCha prototype as it is developed. After development completion the KapCha prototype will be evaluated by means of a summative-naturalistic approach. Summative-naturalistic evaluations will be performed to evaluate the effectiveness of the prototype developed using the model. The summative-naturalistic evaluations will consist of experimental, analytical and descriptive evaluation techniques. The summative-naturalistic evaluation assists in evaluating the performance of KapCha under real-world conditions to address the FSA problems within the case study.

The artificial-summative evaluation will be conducted to evaluate the design of the theoretical model. Artificial-summative evaluations are used to determine the effectiveness of the artefact, and to rigorously establish the benefits derived from the use of the artefact (Venable et al. 2014).

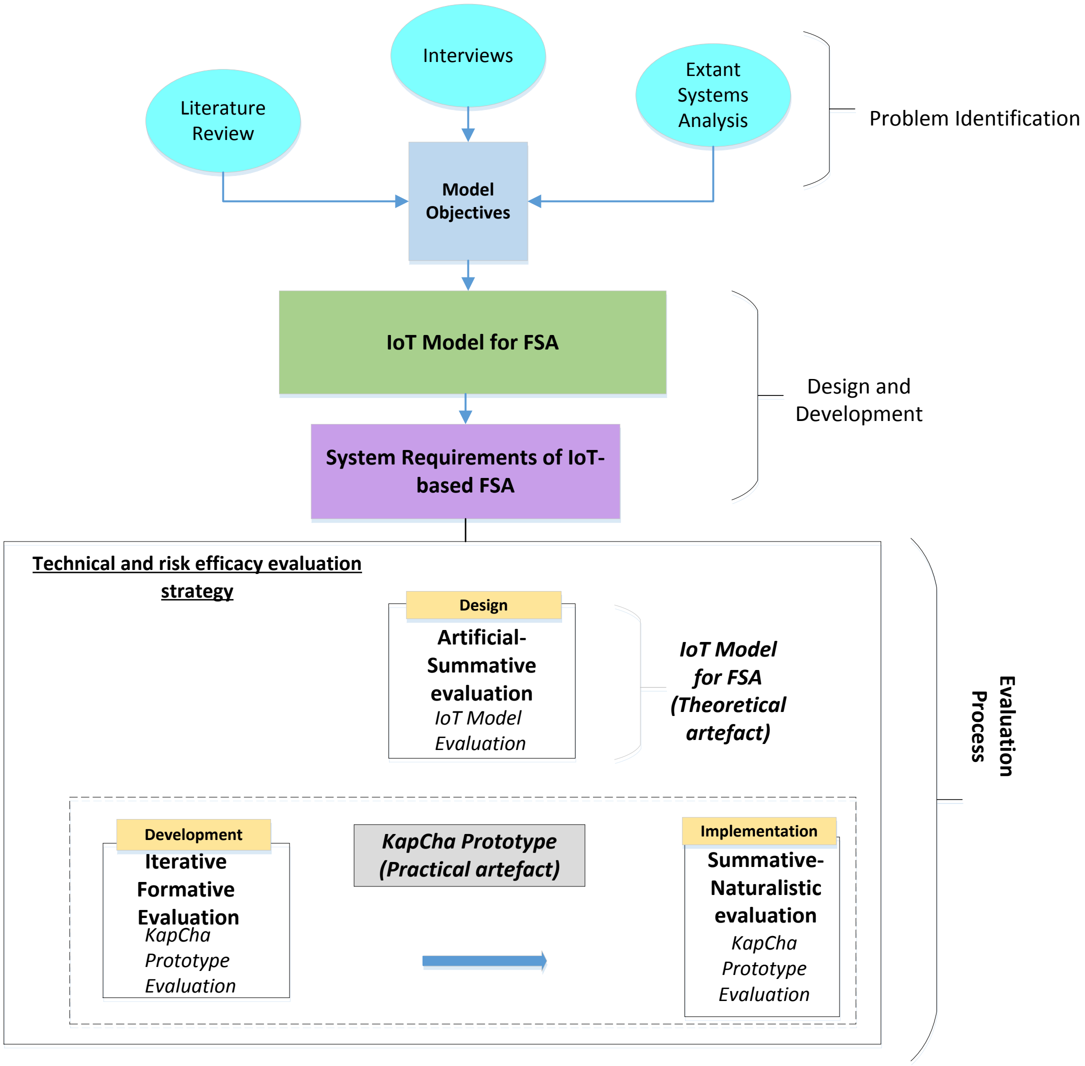

Figure 5-3 Evaluation Process

5.4.3. Design of Individual Evaluation Episodes

Both formative and summative naturalistic evaluations will be used to evaluate the two artefacts namely the IoT model for FSA and KapCha prototype. The evaluation methods will include different evaluation episodes. The evaluation episodes will include evaluation techniques relevant to DSR identified by researchers (Pries-Heje et al. 2008; Venable et al. 2014; Hevner 2007) such as experimental, descriptive, testing and observational (Table 5-3). Four of these are in *italics* in the table and are used in this research, which are:

- Analytical;
- Experimental;
- Descriptive; and
- Testing.

Table 5-3 DSR Evaluation Techniques (Pries-Heje et al., 2008; Vaishnavi & Kuechler, 2015)

Evaluation Techniques	Description
Analytical	• *Static Analysis: Examination of the artefact structure to identify static qualities such as complexity* • *Architecture Analysis: Examination of the artefact fitting into a technical architecture* • *Optimisation: Demonstrate inherent optimal properties of the artefact or provide optimality bounds on artefact behaviour* • *Dynamic Analysis: Examination of the artefact to identify dynamic qualities such as performance*
Experiment	• *Controlled Experiment: Examination of the artefact in a controlled environment to identify qualities such as usability* • *Simulation: Execution of the artefact using artificial data*
Observational	• Case Study: In-depth examination of the artefact in a specific environment • Field Study: Monitor the artefact usage in multiple projects
Descriptive	• *Informed Argument: Information usage from the knowledge base, such as relevant research, to construct a convincing argument for the artefact's utility* • *Scenarios: Demonstration of artefact's utility through well-designed scenarios*
Testing	• *Functional (Black Box) Testing: Execution of the artefact interfaces to identify defects and failures* • *Structural (White Box) Testing: During the artefact implementation, perform coverage testing of a metric such as execution paths*

The evaluation techniques shall be used within the different evaluation episodes. The evaluation episodes will be categorised as per the evaluation methods identified within the technical and risk efficacy evaluation strategy

Formative Evaluation Episode (KapCha Prototype)

Formative evaluations will be conducted during the development of the KapCha prototype and are the first phase of the evaluations (Phase 1). The formative evaluation will be iteratively performed with the objective of detecting and eliminating any potential functional issues. Formative evaluations can be categorised into four categories namely: proactive, clarificative, interactive and monitoring (Table 5-4). Proactive and clarificative evaluations will be used in this study. The literature review (Chapter 3) and the interviews (Chapter 4) conducted were classified as *proactive* types of formative evaluations as they aided in clarifying the necessity of the project through the fulfilment of the second activity of the DSRM model (Section 2.3.3). During prototype development the program logic, *clarificative*, of the prototype shall be assessed through functional testing to identify defects and failures. The formative evaluation will serve as preliminary testing and take place prior to the summative evaluations.

Table 5-4 Formative Evaluation Classifications (Evaluation Toolbox, 2010)

Classification	Stage	Objective	Example
Proactive	Pre-Project Development	Comprehension or clarification on the necessity of the project	Literature Review Stakeholder Analysis Problem or Solution Tree Analysis
Clarificative	Project Development	Establish theory of change on which project is constructed	Log frame Matrix Program Logic
Interactive	Project Implementation	Continual improvement on project design throughout implementation	Informal Interview Expert Reviews Focus Groups Project Diary
Monitoring	Project Implementation	Ensure efficient and effective delivery of project activities	Budget Tracking Time Tracking Questionnaire Dashboard

Summative Evaluation Episodes (KapCha Prototype and IoT Model for FSA)

The second phase (Phase 2) of the evaluations are the summative evaluation episodes and will consist of the summative-naturalistic evaluation (the KapCha prototype) and the artificial-summative evaluation (the model). The summative-naturalistic evaluations will consist of experiments to evaluate the performance of the artefact under near to real-world conditions. Experimental techniques will be used to evaluate the KapCha prototype. Experimental techniques proposed by Pries-Heje et al. (2008) will be used in order to examine the practical artefact within a controlled environment as it is not possible to evaluation all metrics in the real-world. A controlled experiment will be conducted in order to determine the ability of the KapCha web-socket prototype to meet the requirements of an IoT based FSA system. A simulated experimental evaluation of the scalability of the web-socket server and the database centric pattern will also be performed by increasing the number of client connections the server can handle. The accuracy of the decision tree algorithm implemented to determine the root cause of a fault will be evaluated by means of analytical evaluation techniques. Finally, a descriptive evaluation of the security integrity of the prototype will performed.

An interview will be conducted with an industry expert within the field of FSM to evaluate the model as an artificial-summative evaluation. The profile of the industry expert should meet the following requirements:

- Have at least eight years work experience within the field of FSM;
- Should have held a managerial position that allowed him/her to oversee field service activities and tasks; and
- Should have a broad understanding of each of at least two of the three field service tasks identified namely repairs, maintenance and installation.

The participant should meet these requirements in order for him/her to qualify as an industry expert with the expertise to assess each of the components of the theoretical model from a conceptual level. Figure 5-4 summarises the evaluation process by highlighting the three evaluation episodes and the evaluation techniques and criteria to be used during each episode.

Phase 1

Iterative Formative Evaluations Episode		
Artefact	**Evaluation Technique**	**Classification**
KapCha Prototype: (ProtoWebSoc, ProtoObjWeb, ProtoDT	Testing (Functional Testing)	Clarificative

Phase 2

Summative-naturalistic Evaluation Episode		
Artefact	**Evaluation Technique**	**Metric**
KapCha Prototype	Analytical	Accuracy
	Experimental	Performance (Time)
		Scalability
	Descriptive	Security specific conditions adhered to

Artificial-summative Evaluation Episode			
Artefact	**Evaluation Method**	**Criteria**	**Evaluator**
IoT Model for FSA	Structured Interview (TTF based questions)	Successful adherence to FSA system requirements	FSM industry expert

Figure 5-4 Evaluation Process Overview

5.5. KapCha Architecture

During the development of the KapCha prototype the system requirements of an IoT-based FSA were taken into consideration (Section 4.6). The KapCha prototype was developed using the incremental prototyping process (Section 5.3). Three prototypes were developed, namely ProtoObjWeb, ProtoWebSoc and ProtoDT, during the incremental prototyping process. Table 5-5 illustrates the three prototypes developed, their components, the system requirements they each fulfil and the problems from the case study they address.

Table 5-5 KapCha Prototype Mapped to the System Requirements

Prototype	Components/Features	Four Layered Architecture Layer(s)	System requirements for IoT-based FSA	Problems from case study
ProtoObjWeb	Smart light	Object Layer	R1, R7	CP-1,CP-3
ProtoWebSoc	Bi-directional network protocol	Network Layer	R2, R5, R6, R8, R9	CP-1,CP-2,CP-3
ProtoDT	Intelligent algorithm Data storage facility Abstraction interface	Data Storage & Abstraction Layer Applications Layer	R3, R4, R9	CP-4,CP-5,CP-6

The techniques and technologies incorporated in the layers of the KapCha prototype are as follows:

- Objects Layer: A smart light (Section 4.7.2.1);
- Network Layer: A bi-directional network protocol (Section 4.7.3.2);
- Storage and abstraction layer
    - Intelligent algorithms (Section 4.7.2.3);
    - Data storage facility (Section 4.7.2.3); and
- Application layer: REST API (Section 4.7.2.3).

The bi-directional network protocol adheres to the patterns within the transmission phase of the Three-Phase Data Flow Process (Section 4.7.2.2). It is a bi-directional network transmission protocol which provides RTC between a smart object and a central system or other smart objects. The network protocol supports ad hoc and continuous data transfer as well as operational status communication and RPCs. In order for the network to meet these requirements it needs to be bi-directional and fully duplex as calls can be initiated by both the client and the server.

The KapCha system was developed using a database-centric architecture (Figure 5-5). The database-centric approach incorporates the elements from the storage and application layer and the data processing, managing and utilisation phase processes are adhered to. Database-centric is a software architecture where the database is the focal point of all operations. A database provides fault tolerant and reliable transactions. The database-centric approach provides a dependable mechanism to record a large amount of FSA data (Huang, 2013). The approach merges the features of database-centric approach with the demands of FSA services and provides customised features for FSA services. Thus, the approach, firstly, supports heterogeneous and multimedia contents. Secondly, it provides standard APIs for standard web services, and thus the FSA data can be utilised. Finally, live notification is supported and security features are applied.

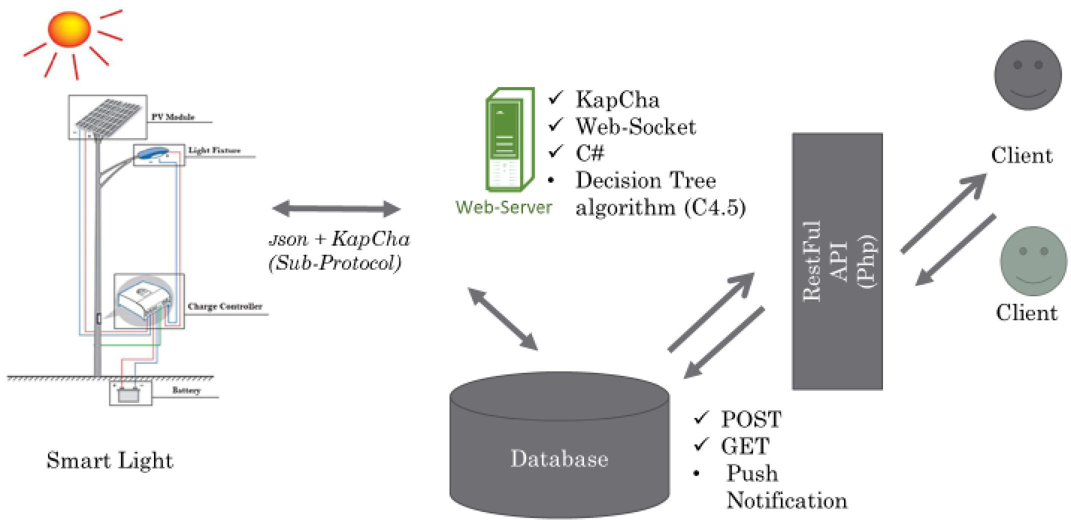

Figure 5-5 Overview of KapCha System Architecture

In the implementation of the KapCha prototype, data is transferred through REST APIs with Web-Socket Requests/Responses. The REST API forms an intermediate layer between a client and the database, which translates the raw data from database to a format that the client requests. As for real-time notifications, most databases have already natively provided notifications for added or updated data. However, the real-time notification passage between the database and the client needs to be defined in the intermediate layer. For example, Ajax techniques such as polling and long polling can be applied. However, in the case of the KapCha system, the interface layer was created using a Web-Socket server, hence eliminating the need for Ajax techniques of polling. The web-socket server manages the web-socket connections after successfully performing the handshake operation itself and the client for purpose of informing the client as needed. A discussion of the development of the KapCha prototype shall presented in the next section.

5.6. Development and Formative Evaluation of the KapCha Prototype

In this section, the development process of the KapCha prototype shall be discussed. Incremental prototyping is the development approach adopted (Section 5.3). A description of the various components within the smart environment of the case study shall be discussed as well as how they interacted.

5.6.1. KapCha Incremental Prototyping

KapCha is the design artefact comprising of three prototypes, each of which focuses on a different aspect of functionality. The three prototypes for KapCha were (Figure 5-6):

- ProObjWeb;
- ProWebSoc; and
- ProDT.

The ProtoWebSoc prototype was developed during the first iteration of the incremental prototyping by fulfilling the following requirements (Table 4-6):

- R2 Provide low cost and secure data exchange protocol;
- R5 Allow for RTC;
- R6 Provide support for RPC and controls capabilities;
- R8 Provide support for security implementation at every level of interaction; and
- R9 Provide a platform for standardisation of protocols, tasks and procedures.

The second iteration involved the development of the ProtoObjWeb prototype. The ProtoObjWeb prototype adheres to the following requirements (Table 4-6):

- R1: Provide support to facilitate data accessibility between an OEMs device/equipment and remote service providers; and
- R7: Facilitate the integration of CPS system principles.

Finally, the third iteration involved the development of ProtoDT which adhered to the following requirements (Table 4-6):

- R3: Use of intelligent algorithms for data analysis and task management;
- R4: Provide the support to enable ability to interface with mobile technologies; and

- R9: Provide a platform for standardisation of protocols, tasks and procedures.

Each prototype is evaluated by means of a formative evaluation individually and then incrementally implemented into the overall KapCha prototype. The iterative process in the development of KapCha is in accordance with the DSR methodology activity, Design and Develop Artefact, and the Design Cycle (Section 2.3.2).

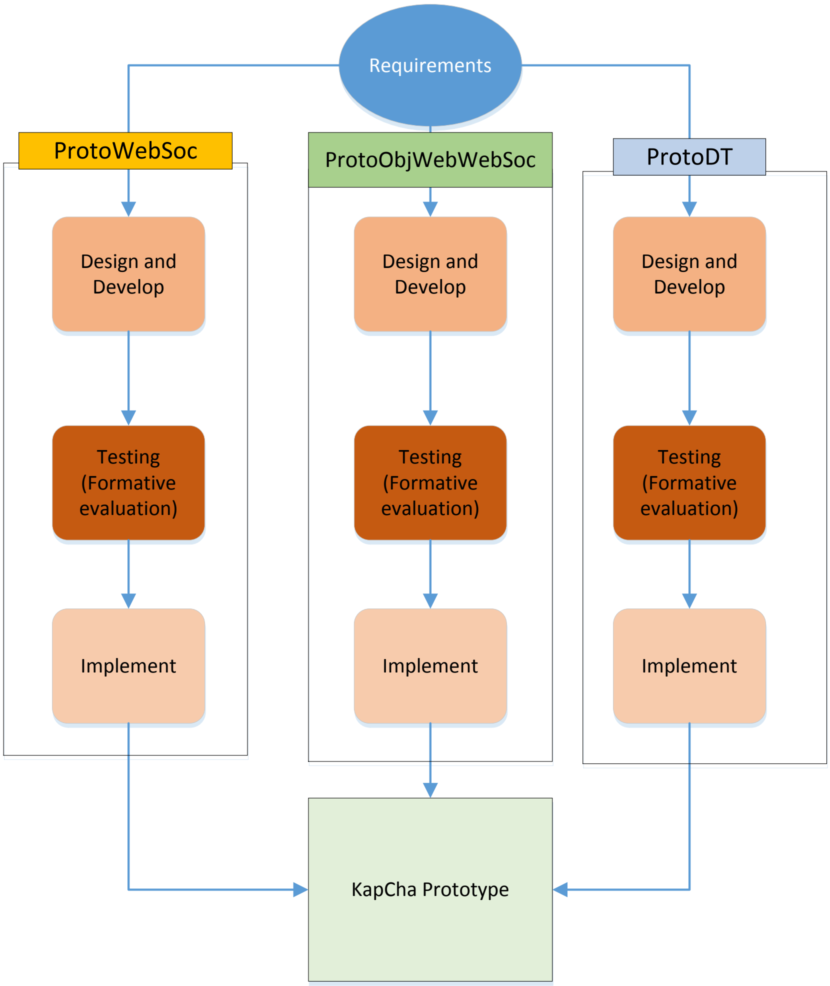

Figure 5-6 Incremental Prototyping Model (Guida et al., 2013)

5.6.2. Iteration 1: ProtoWebSoc Prototype

The first iteration of development focused on developing a data transmission protocol that would be effective for the case study. A formative evaluation was conducted at the end of each development iteration to ensure the prototype addressed requirements R2, R5, R6, R8, and R9 (Table 5-6).

The data transmission protocol should enable real-time bi-directional and low cost communication thus fulfilling R2 and R5. In network environments where data transmission costs are not a constraint the format in which data is interchanged is not a concern for protocols based on SOAP or XML can be utilised. In the case study the communication protocol used is a GSM SMS messaging protocol, therefore each byte that needs to be transferred comes with a cost via the mobile network. An alternative form of a communication protocol which is not restricted by the volume of data transfer constraints was proposed.

A protocol based on JSON was proposed as opposed to SOAP and XML data interchange. The JavaScript Object Notation (JSON), is a text-based open standard that is designed for human-readable data interchange based on Standard ECMA-262 3rd Edition (Bray, 2014). It is a language independent text format that uses conventions similar to programming patterns of the C-family languages including C, C++, C#, Java, JavaScript, Python and many others (JSON, 2014). JSON is used for the serialisation of structured data making it easy for machines to parse and generate it. Serialisation made it ideal for the smart lights within the case study context with low processing computational capabilities. Using the JSON data interchange format will result in less data that needs to be generated as compared to SOAP/XML.

Web-sockets enable two-way communication through the introduction of an interface and the definition of a full-duplex communication channel that operates through a single socket (Fette, 2011). Communication enables upstream and downstream streaming through a single communication channel. Web-sockets provide a reduction in network traffic and latency as compared to polling and long-polling solutions that are used to simulate a full-duplex connection by maintaining two connections. Web-sockets reduces the amount of port openings on the server sides, as compared to the traditional means of retrieving resources such as polling. This entails a reduction in the maintenance of connection channels from the server side, therefore, reducing the overhead network traffic. The Web-socket protocol has the ability to traverse firewalls and proxies which are a problem for many applications.

During connection, the web-socket detects the presence of a proxy server and automatically establishes a tunnel to pass through the proxy. The tunnel is established through the opening of a TCP/IP connection. The connection is established by the client issuing an HTTP connect statement to the proxy server for a specific host and port. Upon the tunnel being set up communication flows uninterrupted through the proxy. A web-socket protocol was designed to work with existing web infrastructure, therefore the protocol specification defines that the web-socket connection starts as an HTTP connection (Lubbers & Greco, 2010). This guarantees full backwards comparability with HTTP based communication protocols. The upgrade from an HTTP to Web-socket is referred to as a handshake. The client sends a request to the server indicating that it wants to switch protocols from HTTP to Web-sockets. The client sends the request by means of an upgrade header which contains the following header fields:

- |Get|- Request-Uri method is used to identify the endpoint of the Web-Socket connection, both to allow multiple domains to be served from one IP address and to allow multiple Web-Socket endpoints to be served by a single server.
- |Host| - the name of the host to be used by both the client and server
- |Upgrade|- states which protocol to upgrade to in this case web-sockets
- |Connection| - states the connection is an upgrade connection
- |Sec-WebSocket-Key| - used as a security verification feature by the client and the server
- |Origin|- used to protect against the unauthorised cross-origin use of a Web-Socket server by scripts using the Web-Socket API in a web browser. If the server does not wish to accept connections from the client origin, it can choose to reject the connection by sending an appropriate HTTP error code
- |Sec-WebSocket-Protocol|- used to indicate what application protocols layers over the web-socket protocol are acceptable to the client. The server selects one or none of the acceptable protocols and echoes that value in its handshake to indicate that it has selected that protocol.

An example of the upgrade request header sent by a client is shown in Figure 5-7.

```
GET /chat HTTP/1.1
Host: server.example.com
Upgrade: websocket
Connection: Upgrade
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
Origin: http://example.com
Sec-WebSocket-Protocol: KapCha
Sec-WebSocket-Version: 13
```

Figure 5-7 Web-socket Request Upgrade Header

During the handshake process the server accepts the request and responds with an upgrade switch header. The server acknowledges receipt of the clients request by taking the |Sec-Web-Socket-Key| value and concatenating it with a GUID in string form. An SHA-1 hash (160 bits) base64-encoded of this concatenation was then returned in the server’s response. This prevents an attacker from tricking a Web-Socket server by sending it carefully crafted packets using

XMLHttpRequest or a form submission. An example of the response from the server is shown in Figure 5-8.

```
HTTP/1.1 101 Switching Protocols
Upgrade: WebSocket
Connection: Upgrade
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
Sec-WebSocket-Protocol: KapCha
```

Figure 5-8 Upgrade Server Response

Web-sockets are ideal due to the ability to use customised protocol calling depending on the service being offered (Fette, 2011). The customised protocol was achieved by setting the Sec-Web-Socket-Protocol header field to "KapCha". When the client received the response with no errors the connection was upgraded to a web-socket over the same TCP/IP connection. The web-socket used ports 80 (standard web-socket). Once the connection was established data frames between clients and servers were transferred. Figure 5-9 provides the researcher's implementation of the handshake process.

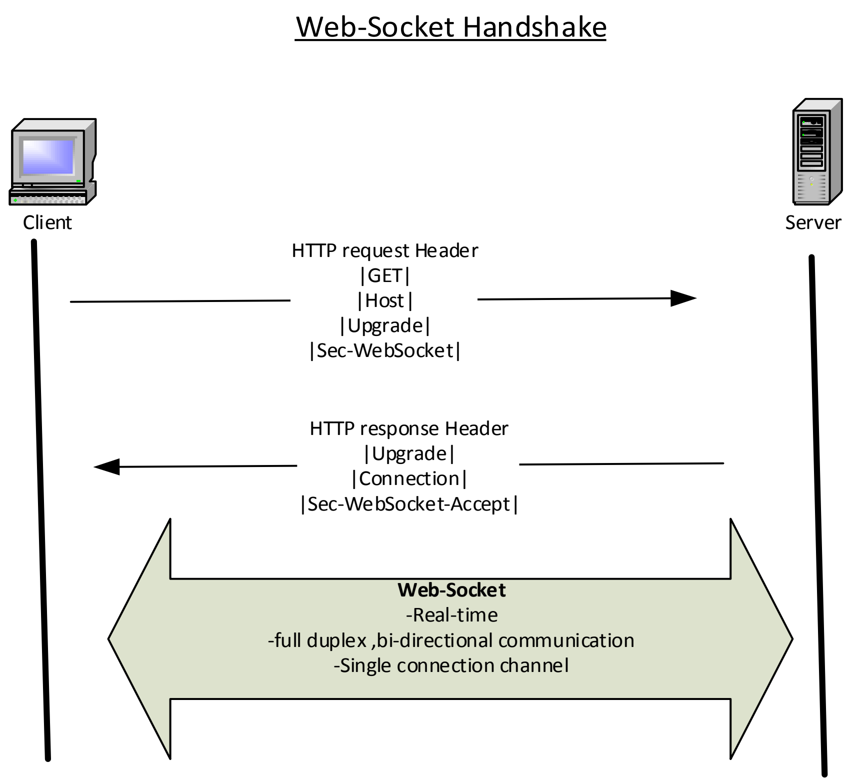

Figure 5-9 Web-socket Connection

Therefore, a combined implemented standard that would use JSON data exchange format over/via web sockets is proposed as the data transmission protocol within the Network Layer.

The second prototype, ProtoObjWeb, focused on converting the data transmission protocol from an SMS based protocol to the web-socket protocol developed during iteration 1. This process shall be discussed in the next section.

5.6.3. Iteration 2: ProtoObjWeb Prototype

The second iteration of development focused on developing a web-socket client application that would enable the smart light to transmit data over the web-socket protocol. A formative evaluation was conducted at the end of each development iteration to ensure the prototype addressed requirements R2, R5, R6, R8 and R9 (Table 5-3).

5.6.3.1. ProtoObjWeb Development

The smart lighting environment in the case study made use of an SMS based protocol to transfer data from a smart light to a server at a remote location. The SMS based protocol as identified through the interview findings was inefficient due to its high latency times and high data costs affiliated with the sending and receiving of SMS messages (Section 4.4). The case study system uses an Arduino microcontroller in each smart light with a GSM Shield which allows the Arduino board to send and receive SMS as well as connect to the internet using the GSM library. The smart lighting system did not use the GPRS wireless component that would enable the Arduino to connect to the Internet. The researcher used the GPRS wireless component to enable the Arduino to make use of web-socket technology.

A web-socket client was developed on the Arduino board. The web-socket client was developed using the Arduino open source software. During development, the limited computational capabilities of the Arduino board was taken into consideration. Therefore the web-socket client made use of the following web-socket methods only:

- OnOpen: Handled the event when the connection is established.OnMessage: Method that receives messages from the server.OnError: Method call is made when there is an error in connection.OnClose: Method call when the connection is closed. OnSend: Method call to send data using the connection to the remote server.
- OnHandShake: Method call to upgrade the connection from HTTP to web-socket and perform a handshake.

Once the web-socket client application connects to the webserver, the webserver initiates an upgrade sequence to upgrade the connection from an HTTP connection to a web-socket server. The OnHandShake method is called once the HTTP 101 response is received. The HTTP 101 response from the server proves the upgrade request. Once the upgrade request has been approved the web-socket client upgrades to the web-socket protocol and communication is initiated. The web-socket client application was functional tested using the web-socket.org echo server.

The web-socket.org echo server allows developers of web-socket applications to test the ability of their applications to successfully upgrade the connection from HTTP to web-socket protocol. The ProtoObjWeb web-application prototype successfully managed to connect to the web.org server and upgrade from HTTP to web-sockets.

The smart light's architecture was not changed as the researcher and participant P6, did not see it necessary to alter the functions and operations. However the format of the data sent to the server over the protocol was changed from a string array to a Json format string. The data was sent in a comma delimited format (Figure 5-10). For easier data processing the format was converted to a JSON comma delimited format (Figure 5-11).

dd-MM-yyyy,HH:mm:ss,TurbineRpm,TurbineWindSpeed,TurbineTipSpeedRatio,TurbineVoltageIn,TurbineCurrentOut,TurbinePowerOut,DutyCycle1,DutyCycle2,DutyCycle3,TurbineMpptLoad,TurbineAutoForced,TurbineStatus,TurbineEnergyToday,TurbineEnergyYesterday,SolarVoltageIn,SolarCurrentOut,SolarPowerOut,SolarMpptLoad,SolarAutoForced,SolarStatus,SolarDayNightStatus,SolarEnergyToday,SolarEnergyYesterday,BatteryVoltage,BatteryChargePercentage,BatteryCurrentInto,BatteryCurrentOut,BatteryStatus,LedCurrent,LedAutoForced,LedStatus,ledOnTimeToday,ledOnTimeYesterday,AuxCurrent,AuxStatus,AuxAutoForced,Temperature,Dipswitch1,Dipswitch2,Dipswitch3,Dipswitch4
12-06-2014,07:00:02,0.00,0.00,0.00,0.00,0.04,0.60,0.00,0.00,620.50,0.00,Auto,MPPT,0.00,15.90,9.07,0.00,0.00,81.25,Auto,Charging Bulk,Day,0.00,314.04,11.56,83.20,0.05,0.05,Battery Charging,0.0,Auto,LED off,0.00,13.45,0.0,Aux on,Auto,-3.32,0,0,0,0

Figure 5-10 String Array Format

```
{
        "dd-MM-yyyy": "12-06-2014,HH:mm:ss:07:00:02",
        "TurbineRpm": 0,
        "TurbineWindSpeed": 0,
        "TurbineTipSpeedRatio": 0,
        "TurbineVoltageIn": 0,
        "TurbineCurrentOut": 0.04,
        "TurbinePowerOut": 0.6,
        "DutyCycle1": 0,
        "DutyCycle2": 0,
        "DutyCycle3": 620.5,
        "TurbineMpptLoad": 0,
        "TurbineAutoForced": "Auto",
        "TurbineStatus": "MPPT",
        "TurbineEnergyToday": 0,
        "TurbineEnergyYesterday": 15.9,
        "SolarVoltageIn": 9.07,
        "SolarCurrentOut": 0,
        "SolarPowerOut": 0,
        "SolarMpptLoad": 81.25,
        "SolarAutoForced": "Auto",
        "SolarStatus": "ChargingBulk",
        "SolarDayNightStatus": "Day",
        "SolarEnergyToday": 0,
        "SolarEnergyYesterday": 314.04,
        "BatteryVoltage": 11.56,
        "BatteryChargePercentage": 83.2,
        "BatteryCurrentInto": 0.05,
        "BatteryCurrentOut": 0,
        "BatteryStatus": "Battery Charging",
        "LedCurrent": 0,
        "LedAutoForced": "Auto",
        "LedStatus": "LED off",
        "ledOnTimeToday": 13.45,
        "ledOnTimeYesterday": 0,
        "AuxCurrent": "Aux on"
}
```

Figure 5-11 Json String Format

Once the development of the ProtoObjWeb was complete a formative evaluation was conducted and this evaluation is discussed in the following section.

5.6.3.2. Formative Evaluation of ProtoWebSoc and ProtoObjWeb

A formative evaluation was performed by mapping the protocol design to the guidelines outlined within the Network Layer of the model and requirements (Section 0). In the case study the microcontroller used in the smart light possess low computational capabilities and hence the web-socket server operating at port 80 enables the microcontroller to connect with the web-socket server with minimal overhead resources required (R1). The JSON data exchange format implemented in the KapCha as opposed to the SMS protocol used in the case study reduces costs of data exchange over a mobile network (R2). An echo test was conducted to evaluate the ability of the smart light to communicate over the web-socket protocol developed during the first iteration (Section 5.5.3). The echo test was also used to assess the ability of the ProtoObjWeb to send and receive data packets using the web-application developed.

The echo test was performed to by sending a JSON message to a web-socket server hosted by websocket.org. The results indicated successful delivery of the data packets through the receipt of the message sent within a sub-second (R5). The receipt of the echo message in the JSON format highlighted the capability of the smart light to receive actuation commands when sent in the same format (R6). The results from the echo tests are shown in Table 5-5.

Table 5-6 Echo Test Results

Echo JSON message	Response from server (Seconds)
Hello	0.6
Hello world	0.6
Web-sockets rock	0.65

ProtoObjWeb through the web-socket client enabled the smart light in the case study, as an OEM, to interface with a remote web-server using the KapCha web-socket protocol (R1). Table 5-6 summarises the fulfilment of the requirements through the development of ProtoWebSoc and ProtoObjWeb.

Table 5-7 ProtoWebSoc and ProtoObjWeb Fulfilled Requirements.

Requirement	ProtoWebSoc	ProtoObjWeb
R1. Efficient for devices with low computational capabilities	Web-sockets operate at port 80 by default	
R2. Enable low cost data transmission	Use of JSON as data exchange format Web-sockets reduce cost through the elimination of polling techniques	
R5. A bi-directional full duplex network protocol	Web-sockets are full duplex bi-directional network technology	
R6. RPC pattern capable	Web-socket RPC calls enabled and capable	
R7: Facilitate the integration of CPS principles		Embedded sensors and actuators within the smart light Transmission of environmental variables from sensors
R8. Secure network protocol	Concatenation of web-socket prevents data-packet intrusion	

The last iteration involved the development of the web-socket server and implementation of the database centric architecture. This was fulfilled through the development of ProtoDT.

5.6.4. Iteration 3: ProtoDT Prototype

The third development iteration focused on the development of the web-socket server application, a decision tree algorithm implementation and a REST API web interface. A formative evaluation was conducted at the end of each development iteration to ensure the prototype addressed the three requirements (R3, R4, R9).

5.6.4.1. ProtoDT Development

The ProtoDT prototype involved the development of the web-socket server application, the database, decision tree algorithms and the implementation of the RestFul architecture using PHP. The software stack implemented is illustrated in Figure 5-12 .

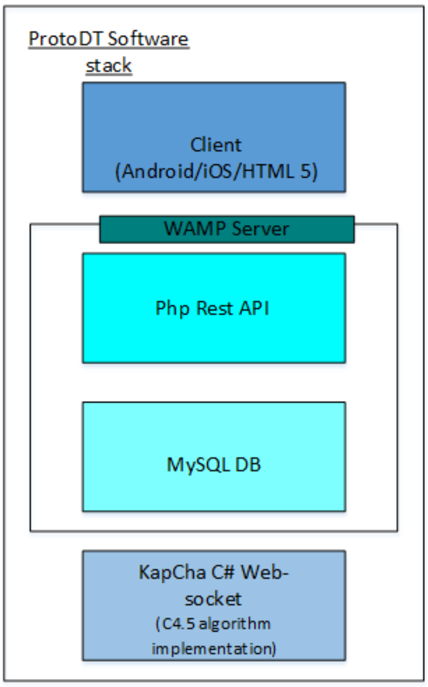

Figure 5-12 ProtoDT Software Stack

The web-socket server was built on top of an existing web-socket library using C#. The web-socket server handles connection requests from clients, that is, the smart lights (Figure 5-13). Multiple threading techniques were used in order to increase application efficiency and reduce wastage of CPU cycles. Each client connection was handled by a new thread.

```
private static async Task AcceptWebSocketClientsAsync(WebSocketListener server, CancellationToken cancellationToken)
{
    while(!cancellationToken.IsCancellationRequested)
    {
        try
        {
            var ws = await server.AcceptWebSocketAsync(cancellationToken).ConfigureAwait(false);
            if (ws != null)
            {
                Task.Run(() => HandleConnectionAsync(ws, cancellationToken));

            }

            else
            {
                eventLog1.WriteEntry("Connection to DB lost");
                ConnectioDB();
            }
        }
        catch(Exception ex)
        {
            eventLog1.WriteEntry("Error accepting clients: " + ex.GetBaseException().Message);
        }

    }
    eventLog1.WriteEntry("Server stopped accepting clients");
}
```

Figure 5-13 Code snippet Web-Socket Server Application

The web-socket server also handled communication with the database. The database is at the core of the application architecture. A WAMP server was used to host a MySQL database. The database consisted of five tables namely: DataReadingTB, SmartObjTB, ServiceTechnicianTB, JobCardTB and IssueReportTB (Figure 5-14).

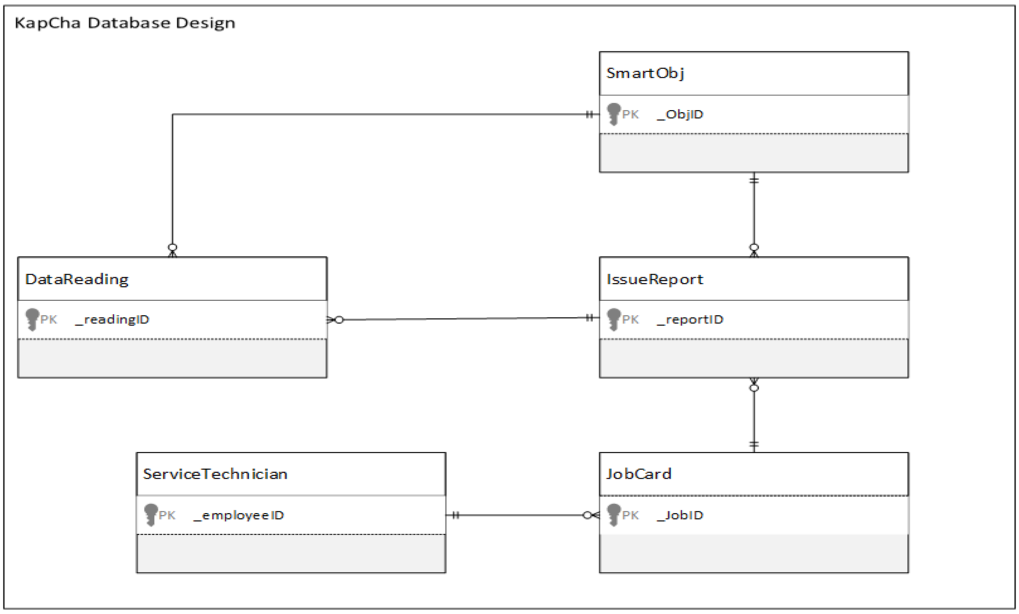

Figure 5-14 KapCha Database Design

The SmartObj table contained information about each smart light such as the date of manufacture and installation, and its GPS location details. The DataReading record stores the data sent by the Smart Light (Figure 5-11). The IssueReport table stored information relating to the fault issue result after data analysis. Once an issue report is generated a job card is created. The job card details are stored in the JobCard table. A job card is then sent to a service technician. In order to generate an issue data analysis using a decision tree learning algorithm was implemented (Section 3.9.1).

The decision tree, AI mechanism, was implemented to provide automated fault diagnosis. The data collected was categorised data and therefore is ideal for decision tree. Furthermore, as there was no historical information on the diagnosis of faults or issues the decision tree was the ideal AI technique to be used as the classifier would be developed from the expert, participant P6 opinion of plausible issues. The diagnosis of a set problems based on the experts' opinion was determined as a classification problem.

Classification is defined as the task of learning target function ***f*** that maps each attribute set **x** to one of the predefined class labels **y** (Tan, Steinbach, & Kumar, 2006). The target function is also called a classification model. A classification model is build using a classification technique. A classification technique is a systematic approach of building a classification model from an input data set (Tan et al., 2006). Examples of classification techniques include decision tree classifiers, rule-based classifier , neural networks and support vector machines just to name a few. Each classification technique makes use of a learning algorithm to identify a model that best suits the relationship between the attribute set and the class label of the input data. A key objective of the learning algorithm is to build models with good generalisation capabilities that accurately predict the class labels of previously unknown records (Tan et al., 2006).

Classification is a pervasive problem that encompasses many diverse applications such as spam email detection, MRI scan cell categorisation and image recognition (Tan et al., 2006). In order to determine the cause of a smart light issue such as the inability for the battery to charge or the LED light not switching on, an examination of the data readings recorded was performed and classification applied. As data was received by the web-socket server application it was pre-processed before being stored in the database. The training data set input used to solve the classification problem of issue identification is presented in Table 5-8.

Table 5-8 Training Data-set

Outlook	SolarDayNight	Battery Out	Battery Current In	Battery Voltage	Solar Voltage In	Turbine Volage In	Issue
Battery Not Charging	Day	0	0,87	13	11,79	0	Battery Full
Battery Not Charging	Night	2,11	0,87	16	11,79	40	Turbine Break
Battery Not Charging	Day	0	0,08	8	19	3	Wiring Solar Connection
Battery Not Charging	Day	0	0,06	7	12	18	User forced abort charge
LED off	Night	2,1	0,06	12,4	0,17	2	LED light Damaged
LED off	Night	0	0,07	11,5	0,01	17	Wiring LED Connection
LED off	Night	0	0,8	8	0	0,01	Battery energy insufficient
LED off	Night	0	2,1	8	0	17	Circuit board damaged
MPPT	Night	0	0,8	11,5	0	20	Circuit board damaged

The LED status and the battery charging status variables were monitored to identify abnormal operational status. For example, if the **LEDstatus** is ***Off*** and yet the **SolarDayNightStatus** variable is ***Night*** then there is an abnormality in the operation of the Smart Light and the data readings will have to be analysed.

The training set consisted of records to build the classification model that was applied to the test set. A decision tree classifier algorithm was then used in the development of the classifier. Ross Quinlan's C4.5 algorithm was implemented in the development of the decision tree classifier. The C4.5 algorithm is an extension of the ID3 algorithm also developed by Ross Quinlan (Sathya & Abraham, 2013). The C4.5 algorithm makes use of Information Gain as a specification hypothesis ordering criteria (Hssina, Merbouha, Ezzikouri, & Erritali, 2014). The information gain measures the gain of information in using each of the attributes as a next factor to consider during the decision. The decision tree developed using the C4.5 algorithm made use of a set of training data. At each node of the tree, C4.5 chooses one attribute of the data that most effectively splits it into a set of subsets. Its criterion was the normalised information gain that is the difference in entropy that resulted from choosing an attribute for splitting the data. The attribute with the highest normalised information gain was chosen to make the decision (Figure 5-15).

$$GainRatio(S,A) \equiv \frac{Gain(S,A)}{SplitInformation(S,A)}$$

$$SplitInformation(S,A) \equiv -\sum_{i=1}^{c} \frac{|S_i|}{|S|} \log_2 \left(\frac{|S_i|}{|S|}\right)$$

Figure 5-15 Gain Ratio and Split Information (Sathya & Abraham, 2013).

Upon identification of the fault, the fault issue was stored in the IssueReport table and a JobCard was created. The job card was sent to a service technician and he/she was notified of it via Google Cloud Messaging. A Php web service was developed as a means of sending the job card to the service technician. The Php we-service API made use of a REST API architecture. The service technician would then view the job card via an Android application. The development of the Android application and management of the Google Cloud Messaging services was out of the scope of this project (Section 1.7). These tasks were undertaken as a component of an honours treatise project within the NMMU Computing Science Department.

The KapCha prototype is to be accessible by end users such as service technicians via mobile devices hence fulfilling requirement R4. A PHP REST API was implemented to fulfil this. The REST API handled communication between the database and web-server, and the mobile devices. The PHP API was thus added a middle layer between the database and the user's mobile devices as provided in the IoT model for FSA between a) the data storage and b) abstraction layer and the Applications Layer (Figure 4-7). The PHP API contains web-service calls to enable actuation commands and retrieval of data. Through the use of POST events actuation commands were sent to the web-socket server. GET request were used to retrieve data from the database such as the last recorded readings from the smart light. Google Cloud Messaging service was used to provide real-time notifications within the REST architecture. The Google Cloud Messaging services provided real-time push notifications of changes in the database. The push notifications alert service technicians with mobile applications of system related changes in the database such as the generation of a new job card.

5.6.4.2. Formative Evaluation ProtoDT

Iterative formative evaluations of the ProtoDT prototype aided in ensuring the prototype met the requirements of the model. The decision tree algorithm was implemented and tested on a dataset provided by engineering firm. It is therefore evident that the requirements were fulfilled (Table 5-8).

Table 5-9 Formative Evaluation of ProtoDT

Requirement	**ProtoDT**
Use of intelligent algorithms for data analysis and task management	Issue detection through the analysis of data using C4.5 decision tree algorithm
Ability to interface with mobile technologies	Use of Php web-service API

5.7. Conclusions

This chapter reported the third activity of the DSRM methodology, the Design and Develop Artefact activity within the Design Cycle of the DSR methodology (Section 2.3.3). Incremental prototyping enabled the quick and easy development of the KapCha prototype. Three prototypes were designed and developed based on the system requirements and the proposed IoT model for FSA. Web-socket technology was used as the underlying communication protocol. It was determined that web-sockets are ideal for web-applications that seek not to use polling mechanisms through the creation of a single socket connection. The socket connection enables full duplex bi-directional communication. Through the development of ProtoWebSoc, a low-cost full duplex data exchange network protocol was developed. ProtoObjWeb illustrated the ability to create a web-client application on an Arduino with a GPRS module. A decision was made to make use of decision trees as an implementation of an intelligent learning algorithm. The design of the model and the prototyping therefore answered the sixth research question in the affirmative:

RQ 6: How can a FSA system be developed using the model?

It is also evident that this chapter succeeded in achieving the seventh research objective:

RO 7: Develop an FSA system (the KapCha prototype) using the model.

The research objectives were achieved through the design of the model and the development of the three iterations of prototypes. The next chapter reports on the results of the evaluations conducted, which addresses the seventh research question.

Chapter 6. Analysis of Summative Evaluation Results

6.1. Introduction

The previous chapter addressed the third activity in the DSR methodology, which is the design and development of the artefacts (the IoT Model for FSA and the KapCha prototype). The chapter also presented the evaluation plan for evaluating the proposed FSA model and the KapCha prototype. The technology and risk strategy of the FEDS framework was adopted as a guide for the evaluation process, which included formative consists of summative, artificial-summative and naturalistic-summative evaluations.

This chapter addresses the seventh research question through the fulfilment of two activities of the DSR process, **Demonstration** and **Evaluation (**Figure 6-1**)** of the artefact:

RQ 7: How can the KapCha prototype optimise FSA within the smart lighting environment in the case study?

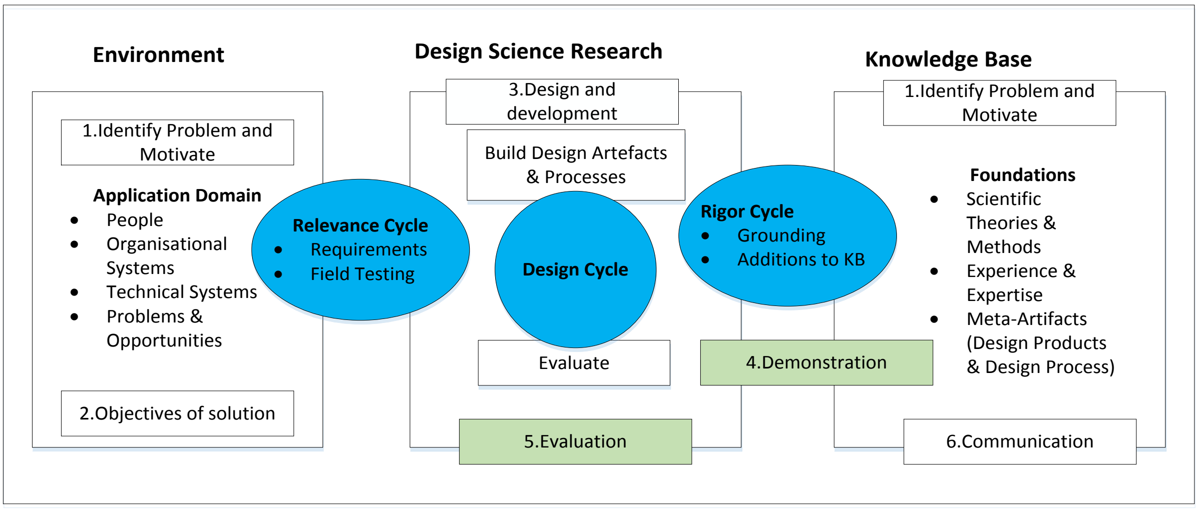

Figure 6-1 Chapter 6 Activities in Adapted DSRM

The evaluation process consisted of two phases (Figure 5-4). The first phase consisted of evaluations of the practical artefact, the KapCha prototype though iterative formative evaluation (Section 5.6). The results of these iteration were reported in Chapter 5. In this chapter the second phase of evaluations, the summative evaluations are reported on and analysed. Summative evaluations of the KapCha prototype and the findings were also conducted (Section 6.2). An artificial-summative evaluation wasconducted by means of an interview (Section 6.6). After completion of the evaluation process an examination to determine if the requirements were fulfilled was conducted (Section 6.7). An analysis of the findings revealed several conclusions (Section 6.8).

6.2. Round-Trip Delay Time Experiment

The Round-Trip Delay time (RTD) experiment is a combination of the time taken for a client to send a signal to a server and the time it takes for the server to acknowledge the signal and send a response. In this context the client was the smart light and the server was the remote web-socket server application. The experiment was conducted to evaluate the real-time network communication ability of the KapCha web-socket protocol (requirements R5 and R6). The aim of the experiment was to evaluate the performance and time metrics through the connection stability and real-time communication ability respectively, of web-socket's single connection as compared to other communication protocols that adopt polling mechanisms such as Ajax with HTTP (Section 4.7.2.2).

6.2.1. Procedure

In order to perform the RTD experiment a connection had to be established between the smart light and the web-socket server application. The following two cycles of the RTD experiment were performed:

- The first cycle (local testing) consisted of running the server applications on a localhost machine within the NMMU Computing Sciences department; and
- The second cycle (remote testing) of the experiment involved running the server applications on a remote server. The local server's IP address was 10.101.120.88 whilst the remote server's IP address was 38.140.140.154.

The web-socket client application was developed during the second iteration of the incremental prototyping, ProtoObjWeb (Section 5.6.3), and an HTML + Java Script web client application developed for evaluation purposes by the researcher were used as clients that sent packets to the server applications. Two server applications were also developed, namely:

- The KapCha web-socket server; and
- The console web-server.

The KapCha web-socket server application was developed during the third iteration of the incremental prototyping process and a C# Console based web-server application was developed prior to the experiment being conducted for evaluation purposes. The two sets of applications namely the web-socket client and server, and the HTTP client and server applications were used to compare web-socket and HTTP protocols. The RTD comparison performed was between the KapCha web-socket protocol and an HTTP-Ajax based protocol. The performance metrics (Figure 5-4) for the RTD evaluation were delay time and messages per second. The experiments procedure involved running the applications in three iterations, the first iteration involved sending a data packet 10 times, then the second iteration a 100 times and the third iteration a 1000 times. The data packet was an array data object which was instantiated and sent to the server during the three iterations.

6.2.2. Results

The results of the three iterations of the first cycle are displayed in Table 6-2.

Table 6-1 Localhost Testing Web-sockets vs Ajax

Iterations	**Ajax**		**Web-socket (KapCha)**	
	Time (sec)	Messages (per sec)	Time (sec)	Messages (per sec)
10	0.130	80.135	0.082	150.235
100	0.435	301.720	0.082	1502.35
1000	3.104	340.832	0.558	2215.621

From the results for all three iterations obtained it is evident that the KapCha web-socket had a lower RTD time as compared to the Ajax protocol. The results can be attributed to the fact that there are fewer HTTP overheads when using web-sockets as compared to Ajax requests. Upon the connection being established all messages are sent over the single socket connection rather than the creation of new connections for new HTTP request and response calls created every time a message is sent over the Ajax protocol (Figure 6-2). Furthermore, the web-socket based protocol had more messages sent per second as compared to that of the Ajax protocol. The messages per second for web-sockets are higher because the web-sockets establish the connection once over a single socket and unlike HTTP-Ajax techniques that require multiple connection to be opened and closed during request/response calls. Therefore web-sockets do not have messages delayed during the connection process and will send more messages per second. The messages sent per second over the web-socket protocol increased exponentially with the number of iterations completed (Figure 6-3).

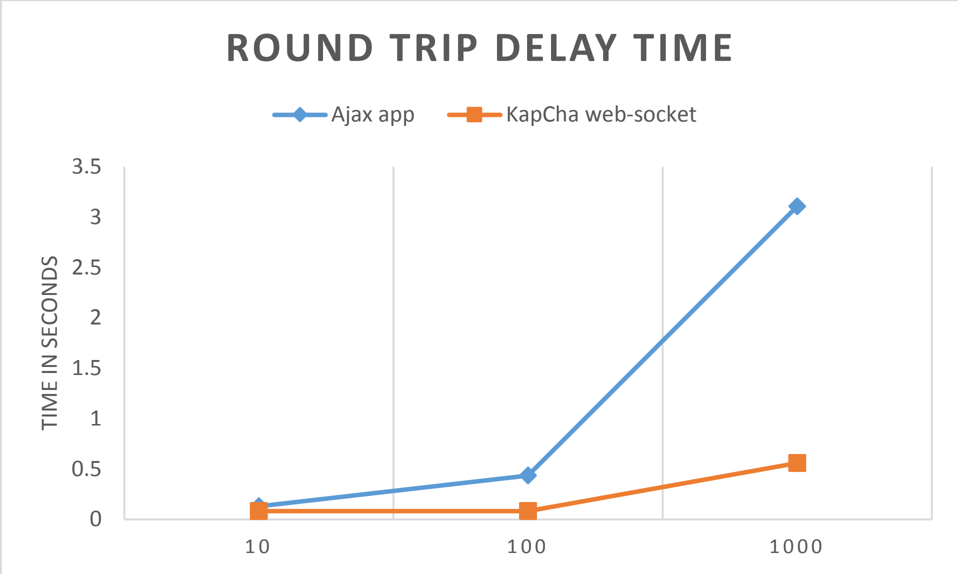

Figure 6-2 RDT Ajax vs KapCha Web-sockets

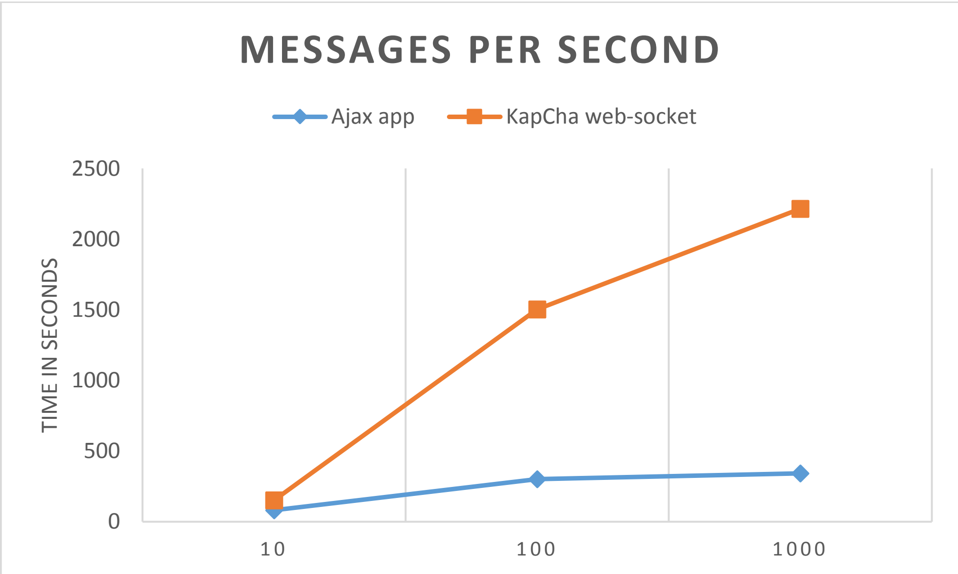

Figure 6-3 Ajax vs KapCha Web-sockets Messages per Second (Localhost)

The same experiment was conducted in order to assess the effect the latency that is the time it takes for a packet of data to get from one designated point to another, has on the two protocols. Latency could not be determined by performing the experiment on the localhost machine because the distance between the client and the server was not taken into consideration. The server application was hosted on a server in Washington DC, USA whilst the client applications were run from the researcher's desktop at the NMMU Computing Sciences department in Port

Elizabeth. The second cycle was run under the same conditions as the former, that is, there were three iterations performed and the same array object was sent from the clients to the server (Table 6-3).

Table 6-2 Ajax vs KapCha Web-socket Remote

Iterations	Ajax		Web-socket (KapCha)	
	Time (sec)	Messages(per sec)	Time (sec)	Messages (per sec)
10	01.241	3.212	3.705	1.752
100	22.016	2.907	17.213	3.352
1000	153.352	3.191	147.25	3.714

The results from the second cycle revealed that the web-socket protocol had a lower RTD time as compared to the Ajax protocol in two of the three iterations of testing (Figure 6-4). However, within the first iteration, the Ajax call had a lower RTD time. The result could be alluded to the upgrade sequence overhead during the web-socket handshake process. This additional overhead connection, however, is not significant as the number of iterations increase due to the maintenance of the single socket connection.

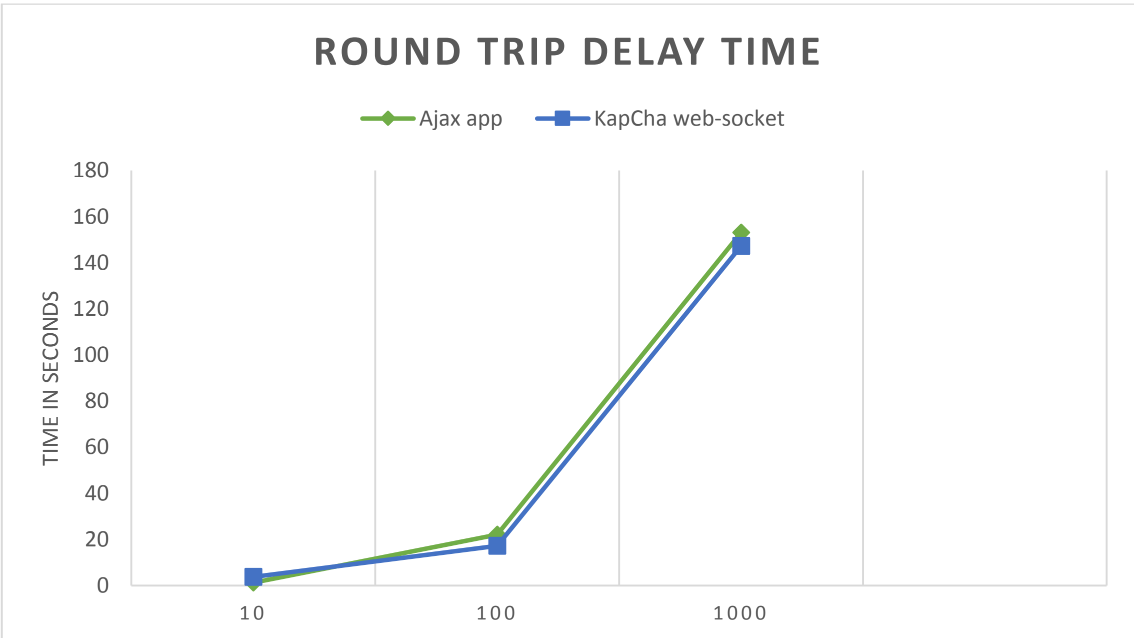

Figure 6-4 RDT Remote Location

The results of the messages per second follow the same precedent as the first cycle of the experiment, with the web-socket protocol having a higher success rate of messages delivered. However, similar to the RTD of the first iteration of second cycle (Figure 6-4) the messages per second is higher than that of the web-socket protocol (Figure 6-5). The researcher attributes this pattern to the upgrade overhead during initial connection of the web-socket protocol.

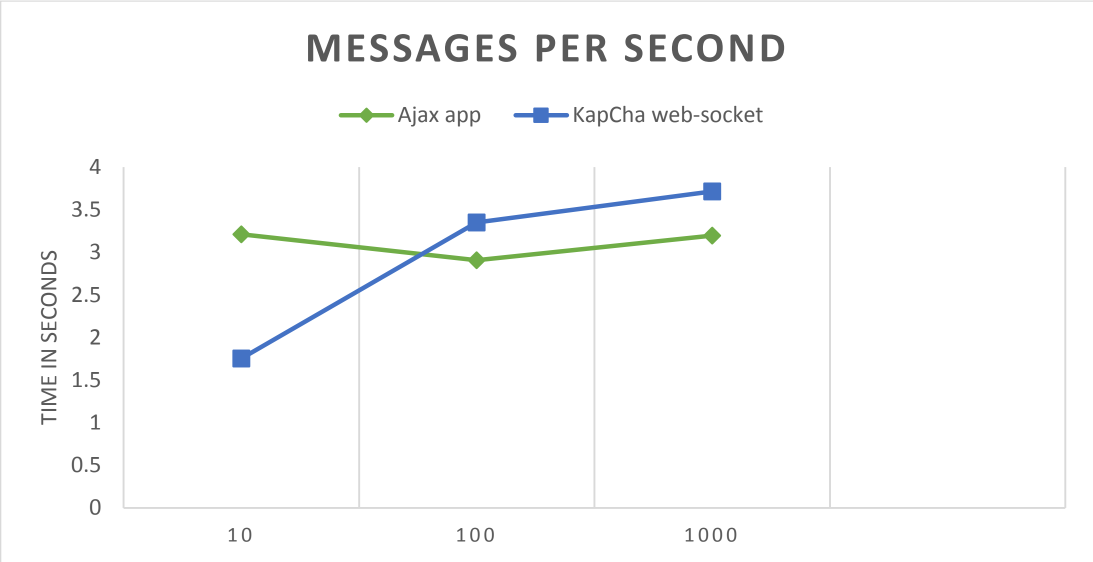

Figure 6-5 Messages per Second Remote Location

The results of the RDT experiments highlight the advantages that applications using web-sockets have over HTTP polling mechanisms such as polling. The advantages include lower latency and the ability to maintain a single socket connection which enables the web server to push data to the client at will, creating a fully duplex bi-directional data exchange web-protocol.

6.3. Scalability Experiment

A simulated experiment was conducted to evaluate the scalability of the KapCha prototype. Scalability testing is a performance testing metric that investigates a system’s ability to grow by increasing the workload per user, or the number of concurrent users and the size of the database (Huang, 2014). The performance evaluation by means of scalability testing, was performed in order to access the ability of the system to grow and handle requests from many users’ clients. Scalability is crucial within the IoT environment as there will be many devices connected to a remote server and this is applicable to the smart lighting environment within the case study.

6.3.1. Procedure

During the experiment, two client applications were developed, that is:

- A web-socket C# console application; and
- A light switch C# program that runs on a Raspberry Pi.

The web- socket C# client console application was developed and run multiple times to replicate artificial smart lights connecting to a server. Once the console application successfully established a connection the application echoed its ID and the text “hello world”. The C# lightswitch application simulated a smart light that was receiving commands from the server application. The lightswitch application triggered an event to switch on an LED light connected to a Raspberry Pi via a breadboard.

The KapCha web-socket server application developed under the ProtoDT prototype (Section 5.6.4) was required to handle multiple connections (Figure 5-13). The KapCha application implemented the Pub/Sub and RPC design patterns (Section 0). By implementing the Pub/Sub and RPC patterns the web-socket adequately managed to send commands and transfer data within the KapCha prototype. The scaling experiment required the server to address each of the clients individually through the handling of their various requests.

In order to evaluate the effective implementation of the RPC pattern, commands to switch the LED light on and off were sent to the light switch application. The Publish/Subscribe pattern was assessed by the KapCha prototype’s ability to transfer between the clients and the server as the number of clients increased. A single instance of the client application was run/deployed as the number of C# console applications increased. The results of the experiment ae discussed in the section below.

6.3.2. Results

The results from the experiment are shown in Table 6-3. From the results obtained it can be deduced that the response time of the light being switched on was not affected by the increase in the number of applications connecting to the server. The response time for the first ten client applications (n=10) was 0.3 seconds. However, upon increasing the number of client applications to twenty (n=20) the response time almost doubled to 0.5 seconds. The experiment was left running for 24 hours after which a console application was run/deployed. The client instantiated was the twenty first (n=21) and the echo response time was 0.5 seconds. The result suggested that the running of the client applications and the server did not thoroughly affect the CPU usage of the computer used by the researcher. The increase in the echo response time suggests that with an increase in the number of applications the KapCha web-server application will have an increase in the response time. An echo response time of less than a second is deemed reasonable as it is still within the context of real-time. The scaling was also successful due to the fact that the communication between the clients and the server was maintained during the duration of the entire experiment. Each client (as addressed as per its client ID) therefore successfully adhering to the Publish/Subscribe and RPC patterns.

Table 6-3 Scalability Results

No. of C# console applications	Echo response time (seconds)	Light switch response time (seconds)
1	0.3	0.4
2	0.3	0.4
3	0.3	0.4
10	0.3	0.4
20	0.5	0.4
21	0.5	0.4

The researcher however predicts that with a computer with higher performance features the response time would be less. The researcher was running the experiment on a Windows 7 computer with 6 GB RAM and an i3 Intel manufactured processor. As for the database-centric pattern, the KapCha prototype solution provided a reliable and flexible way to scale horizontally and to replicate, with the growing amount of data. The architecture design of the KapCha prototype could also be deployed into a cloud-based architecture which would maximise its scalability.

6.4. Decision Tree Analytical Evaluation

The use of AI or ML mechanisms was identified as a requirement of an IoT-based FSA system (Table 3-8). The information presented by AI or ML mechanisms aid in the completion of task of fault diagnosis, requirement R3 (Section 3.9.1). It is therefore important to access the information presented by these techniques. A decision tree was implemented in order to determine fault diagnosis of a fault that arises within a smart light. The decision tree identified the possible issue through classification based on an evaluation of various variables recorded by the sensors from the smart light.

6.4.1. Procedure

Accuracy is the measurement of a quantity to that quantity's truth value to the degree of familiarity (Hssina et al., 2014). The accuracy metric was used to determine how well the decision tree performed in terms of the accuracy of the information presented by the decision tree. The formula used for accuracy was:

$$\text{Accuracy} = \frac{\text{Number of correct predictions}}{\text{Total number of predictions}} = \frac{f_{11} + f_{00}}{f_{11} + f_{10} + f_{01} + f_{00}}.$$

Equation 1 Accuracy Formula (Tan et al., 2006)

The C4.5 decision tree algorithm was deployed/executed on three sample data set sizes. Data sample sizes were 50, 100 and 175 the algorithm was executed to analyse each data set. The number of correct predictions after each execution were recorded. The correct predictions were verified by participant P6. Prior to the development of the KapCha prototype there wasn't any data stored regarding the cause of a fault or the documentation of the diagnosis of a fault within the case study. Therefore the accuracy of the training dataset (Table 5-8) upon being created was based on participants P6's verification as an expert user of the system. The C4.5 decision tree algorithm was used to analyse the historical data and deduce the cause of the faults that had occurred. This process was undertaken to establish the accuracy of the algorithm in diagnosing faults. The execution time of the algorithm was also recorded to determine the turnaround time of the fault diagnosis.

6.4.2. Results

The accuracy results from the decision tree analytical evaluation were presented as a percentage and are presented in Table 6-4. Equation 1 was used to determine the accuracy percentage. The sample size of fifty (n=50) resulted in a percentage accuracy of 82.2% meaning that 41 out of the 50 predictions were correct. The sample size of 100 had 79 correctly predicted faults with a percentage accuracy of 79%. The final sample size had an accuracy percentage of 77% that is 96 faults were correctly predicted.

Table 6-4 Accuracy Results of C4.5 Decision Tree Algorithm

Size of Data Set	Accuracy result (%)
50	82
100	79
125	77
Mean	**79**

The execution time of the algorithm for all three sample data sets was less than 1 second (Figure 6-6). The data set sample size of fifty (n=50) had an execution time of 0.03 seconds and the data set sample size of one hundred (n=100) had an execution time of 0.1 seconds. The third data set with 125 records had an execution time of 0.12 seconds. The execution times of less than a second reflect the turnaround time of fault diagnosis with the case study to less than a second.

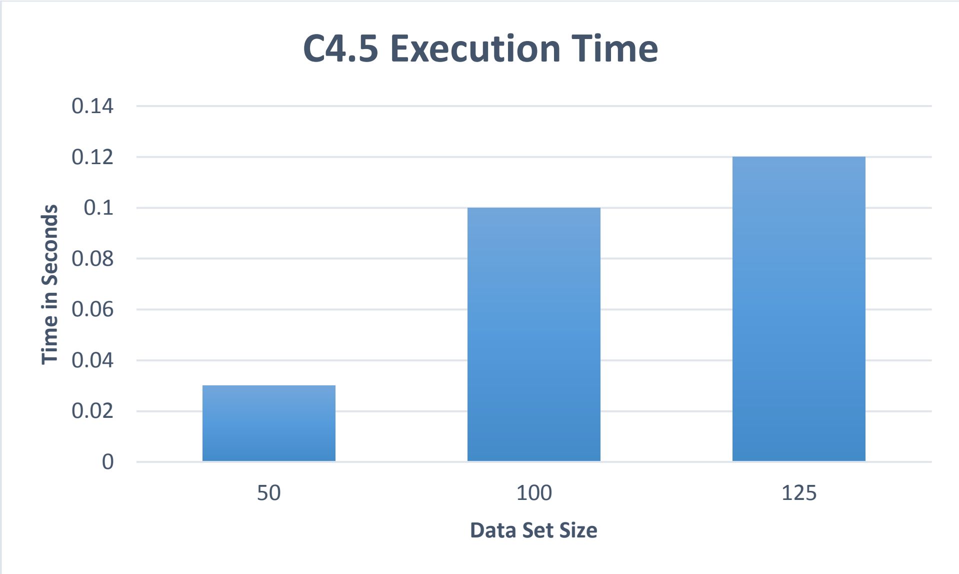

Figure 6-6 Execution Time C4.5 Decision Tree Algorithm

As can be observed the accuracy percentage of the results derived decreased slightly with an increase in the size of the data set. The increase can be alluded to the unaccounted for faults that were not identified by the participant P6 (Table 4-1), during the generation of the classification model. However, the high turnaround rate and the 79% average accuracy percentage, the accuracy evaluation results of the decision tree can be considered successful.

6.5. Security of KapCha ProtoType

The descriptive evaluation method (Table 5-5) was used to evaluate the security metric of the KapCha prototype. The descriptive evaluation was achieved through the theoretical analysis of the security concerns identified in the literature review implemented (Section 3.8.1). The KapCha prototype made use of web-socket technologies as its underlying data exchange protocol. Web-sockets provide the following security considerations:

- Web-socket connections are made over Transport Layer Security (TSL) (Fette, 2011). TSL provides communication security over the Internet (Fette, 2011; Lubbers & Greco, 2010)

- Web-Socket protocol prevents malicious applications running inside a web browser through non-browser client resistant mechanisms (Huang 2013).
- Origin considerations: The web-socket protocol provides a way for servers that do not intend to process input from web pages from other origins (Fette, 2011).
- Masking: All data from clients to servers are masked so that the attacker does not have knowledge about how the data being sent (Green, 2014).
- Sub-protocol header: Through the sub-protocol header provides an authentication security feature (Vinay & Boulanger, 2016). By issuing a sub-protocol version only known to the client the server will not authorise the handshake process and therefore allowing the establishment of the socket connection.

Furthermore, other security considerations were implemented through the database-centric pattern. Session-based authentication was implemented within the KapCha prototype. Clients once authenticated with their credentials were issued a temporary session_ID. The session_ID was stored in a hashmap on the server side. The database-centric approach dictates that all authentication occurs server side (Huang 2013). For each request, the client made the session_ID was used as an authentication token. A client's authentication was validated before the request could be executed.

The security considerations were implemented to achieve R8 of the requirements of an IoT-based FSA system that were identified (Table 4-6). The fulfilment of the requirements listed in Table 4-6 is discussed in the next section.

6.6. Artificial Summative Evaluation of IoT for FSA: Interview

An objective of artificial summative evaluations is to determine the efficacy of an artefact (Venable et al., 2014). The objective was achieved by proving that the benefits of using the artefact are due to the artefact, not other factors. The efficacy of the model was evaluated by its ability to support the tasks within the field services domain. This evaluation can be done by matching the capabilities of the technologies the model presents to field service tasks (Section 3.2; 4.2). The Task-Technology Fit (TTF) theory is an evaluation approach that maps the task to the technology.

The TTF model aids in understanding the impact technology has on an individual's ability to execute tasks (Irick, 2015). TTF proposes that technology will be used only if the tasks available to the user fit the activities of the user (Klopping & Mckinney, 2004). In order for an information system or technology construct to be used it should have a positive impact on individual performance and there must be a good fit with the tasks the technology supports (Irick, 2015). The model proposed IoT model for FSA is a theoretical construct and can therefore be evaluated using the TTF model. The characteristics of the model were matched against field service tasks such as repairs and maintenance using an interview. The interview was conducted with a managerial participant (P2) with the specified level of expertise (Section 4.3.2). The requirements for the participant to evaluate the model consisted of the following:

- Have at least eight years work experience within the field of FSM;
- Should have held a managerial or supervisor that allowed him/her to oversee field service activities and tasks; and
- Should have a broad understanding of each of at least two of the three field service tasks identified namely repairs, maintenance and installation.

Participant P2 from the HEI maintenance services has fifteen years work experience within the field of FSM and serves as the deputy director of the HEI maintenance services. His job description involves him overseeing maintenance, repairs and installation tasks within the university. With his fifteen years' worth of work experience participant P2 not only has a broad understanding of field service tasks but also meets the requirements of a participant to evaluate the model. Table 6-5 illustrates the questions asked during the interview. The dimensions related to the different requirement characteristics to be fulfilled during the execution of each task.

Table 6-5 Task Technology Fit Interview Questions

High-level overview questions		
1. Does the model meet the expected requirements of a FSA system? (have all design considerations been met)		
2. What are the positive features of the model?		
3. What are the shortcomings or negative features of the model?		
4. Is the user of the opinion that developing a system from the model is feasible?		
5. What suggestions if any can the user provide to improve the model?		
Dimension	**Task**	**Question**
D1: Real-Time Data accessibility	Maintenance	Do you believe this model would allow maintenance users to gain data within a reasonable time frame through the suggested protocols and access to OEM's?
D2: General Data accessibility	Maintenance	Do you believe this model would facilitate access to data that the maintenance user needs? e.g health status of equipment
D3: Real-Time Data accessibility	Repairs	Do you believe this model would allow repair users to gain data within a reasonable time frame through the suggested protocols and access to OEM's?
D4: General: Data accessibility	Repairs	Do you believe this model would facilitate access to data that the repairs user needs? e.g health status of equipment

D5: Intelligent system algorithms(AI)	Repairs	Would the model reduce downtime through the use of AI techniques for fault diagnosis?
D6: Downtime	Repairs	Would the model reduce downtime through the reduction in onsite time?

The interview identified the tasks performed by field service organisations as well as the impact the characteristics of the model would have on the tasks. The interview questions were an adaptation of a TTF measurement instrument developed by Goodhue (1998). The participant P2 was asked the TTF questions in order to provide structure for the semi-formal interview conducted[1] (Johannesson & Perjons, 2012). An analysis of the interview responses is provided in this section. The TFF questions consisted of high level overview questions and FSA task related questions.

High Level Overview Questions

In the first part of the interview the participant was asked the following high level overview questions:

Question 1: Does the model meet the expected requirements of a FSA system (have all design considerations been met)?

Asked is the participant believed all the requirements of an FSA system were met during the design of the model the participant responded with an affirmative.. "*Yes*"

The participant's response was affirmative and he confirmed indicates that the requirements of an FSA system were considered during the design of the IoT model for FSA.

Question 2: What are the positive features of the model?

The participant's response to the second question was "..*It is a practical model especially for industry, as they are already using automation devices to feedback to the offices. It assists with the resource scarcity in terms of human and intellectual capital. With limited skilled technicians, the model allows for semi-skilled technicians to be deployed to attend to the issue with the assistance of the intelligence provided.*"

[1] Appendix C

The participant's response indicates that the model is practical for the field service industry as there are automation devices used to provide feedback to the service organisations offices. The participant also highlighted that the model could assist with the efficient usage of human and intellectual capital. Semi-skilled technicians can be deployed to attend to issues that would ideally been handled by skilled technicians with the aid of the intelligent systems in cooperated.

Question 3: What are the shortcomings or negative features of the model?

When the participant P2 was asked to state the shortcomings or negative features of the model to which he duly responded "..*Due to the intelligence of the model equipping the artisan with the knowledge of an issue prior the visit to the equipment – the implementation thereof will be expensive because being able to feedback that type of intelligence will require monitoring of many aspects on the equipment."*

The participant's response to the third question indicates that the establishment of a FSA system based on the model would require a high capital investment; which he perceived as a negative aspect of the model.

Question 4: Is the user of the opinion that developing a system from the model is feasible?

When the participant was asked whether he was of the opinion that developing a system from the model was feasible he responded "..*The model is beneficial for the investment cost if it is used for remote sites by speeding up the remedial process. However, it might not be feasible for an HEI's, where all the equipment sites are within close proximity, although it would speed up the turnaround time."*

The participant believed high financial investment would be a barrier for the feasibility of such a model for service organisations which do not have geographically dispersed sites such as HEI. He nevertheless believed the system would speed up the turnaround time of task execution.

Question 5: What suggestions, if any, can the user (you) provide to improve the model?

The participant's response to the question on providing suggestions to improve the model was transcribed as follows "..*The model would require the availability of scarce resources, where every artisan has access to mobile devices. This would be more beneficial if it is utilised by artisans instead of having only management involved. The model should allow for managers to have direct communication with artisans as they are in the field working onsite. Thereby allowing mangers or* *supervisors to provide expert advice or assist in decision making. For instance, have a live chat room session during the execution of a repair task*."

The participant suggests extending the functionality of the model to allow for managers or supervisors to have direct communication with service technicians via the model's technologies. The participant provided an example of having a live chat session during execution of tasks by the service technicians.

FSA Task Related Questions

The model was also asked questions relating to the FSA tasks addressing the six TTF dimensions (D1 to D6). The participant's responses are discussed in the subsequent paragraphs.

The participant believed the model would allow maintenance users to access data within a reasonable time frame through the implementation of the suggested protocols as well as access to OEM's equipment (D1). He also acknowledged that an interface that allows the maintenance users to access equipment information on request such equipment health status would enhance data accessibility (D2). The participant additionally highlighted that the ability to access equipment data would enable the organisation to make strategic decisions such an identifying which service parts to acquire. For example, through the monitoring of equipment performance after maintenance, management can access the quality of service parts acquired in improving equipment operational life.

The participant was of the opinion that the model would facilitate data accessibility in real-time as well as the provision general equipment operational status (D3). He was of the opinion that the accessibility of general equipment operational status data in the context of repairs would reduce the downtime caused by equipment failure (D4). The participant was also of the opinion that the use of AI techniques would reduce the downtime as these techniques would aid in root diagnosis before the artisan got on-site thereby reducing on-site time (D6). He alluded to the fact that the use of the intelligent mechanisms would enhance artisan utilisation (D5). For example, with issue report generated can enable artisans who may not high expertise in fault diagnosis of the certain systems to work on them as the need for expert diagnosis would have already been performed. Participant P2 also acknowledged that systems developed based on the model would reduce the downtime. This can be achieved through the reduction of on-site time as a result of root cause analysis and the ability to review repeat faults which could be rectified in a shorter period of time.

The participant was of the general opinion that the model meets the requirements of a FSA system that can aid in the optimisation of FSA. The participant identified the use of intelligent algorithms for issue detection and the ability for bi-directional communication that facilitates remote actuation as positive features of the model.

The interview findings revealed that the model does fit the field service tasks overall. The participant was satisfied with the optimisation possibilities that the model presents to FSA. In order to consolidate the evaluation process, the procedures and results of the KapCha prototype evaluation are discussed in the next section.

6.7. Fulfilment and Analysis of Requirements

Through the literature study, existing systems analysis and interview findings, the objectives and requirements for the optimisation of FSA as well as the problems faced by FSM within the practice were identified (Figure 4-3). Through the design of the model and its implementation by means of the KapCha prototype, the requirements for a FSA system were fulfilled. The IoT model for FSA established the elements to be found within the IoT-based FSA ecosystem which incooperates techniques and technologies of IoT. The various elements within each layer of the model's architecture were identified as well as their role within the FSA ecosystem. The model identified the use of patterns such as Pub/Sub and RPC procedures within the Network Layer to provide network protocol efficiency.

The KapCha system provided an OEM interface, by means of a web-socket client application, that enabled bi-directional data transfer between the smart light and the web-server. The KapCha web-socket communication protocol was a low-cost data exchange protocol implemented within the KapCha prototypes ecosystem. A decision tree algorithm was implemented as an intelligent algorithm that performed fault diagnosis tasks. The objective of the fault diagnosis was to reduce the downtime through the minimisation of on-site time. The fault diagnosis report provides a service technician with a diagnosis of the fault, therefore, reducing the time spent on on-site diagnosis. The KapCha prototype also implemented PHP REST web-services which facilitate mobile applications to interface with the prototype.

The results of the RTD time experimental evaluation illustrated that the KapCha protocol which is a sub-protocol of web-sockets was a robust bi-directional full duplex communication protocol. Further experiments conducted to evaluate the scalability of the KapCha system also yielded positive results with the system able to handle multiple client connections efficiently. The 79%

mean accuracy percentage result and the sub-second average execution turnaround time highlight the successful implementation of the decision tree in the plausible diagnosis of faults. Through the descriptive evaluation of the security considerations of the KapCha system, the non-functional requirements of the FSA system were also achieved. Table 6-6 highlights the system requirements for an IoT-based FSA (Table 4-6) and the problems addressed from the case study by the KapCha prototype (Table 4-5).

Table 6-6 Fulfilment of System Requirements and Problems Addressed from Case Study by KapCha Prototype

System requirements for IoT-based FSA	KapCha prototype	Problems from case study addressed	KapCha prototype
R1 Provide support to facilitate the data accessibility between an OEM's device/equipment and a remote service provider	✓	CP-1/P5: Lack of real-time data transfer	✓
R2 Provide low cost and secure data exchange protocol	✓	CP-2: High data transmission costs	✓
R3 Use of intelligent algorithms for data analysis and task management	✓	CP-3: Communication protocol half duplex	✓
R4 Provide the support to enable ability to interface with mobile technologies	✓	CP-4: Inability to diagnose problems remotely due to the lack of data processing	✓
R5 Allow for RTC	✓	CP-5/P4 Lack of integration with enterprise systems	✓
R6 Provide support for remote procedural call and controls capabilities	✓		
R8 Provide support for security implementation at every level of interaction	✓		

The interview findings of the artificial-summative evaluation highlighted the following positive aspects of the IoT model of FSA:

- The model would allow maintenance users to access data within a reasonable time frame through the implementation of the suggested protocols;
- The model would assist management in making strategic decisions with the information provided by the model such as identifying which service parts to acquire;
- The model would facilitate data accessibility in real-time as well as the provision of the operational status of general equipment;
- The model would facilitate accessibility of operational status of general equipment data which in the context of repairs would reduce the downtime caused by equipment failure; and

- The use of AI techniques would reduce the downtime as these techniques would aid in root diagnosis before the artisan got on-site thereby reducing on-site time.

The interview findings also highlighted areas of concern such as the implementation of a system based on the model requiring high financial investment. The interview findings also reported the high financial investment would be a barrier in the implementation of a system based on the model in field service organisations that do not have geographically dispersed clients or institutions with facilities within a central location like the HEI. The KapCha prototype was a proof-of-concept application developed based on the IoT model for FSA and the system requirements of an IoT-based FSA system.

6.8. Conclusions

This chapter reported the fourth and fifth activities of the DSR methodology, namely demonstration and evaluation of the artefact. The theoretical artefact, the IoT model for FSA, was demonstrated through the development of the practical artefact, the KapCha prototype. The KapCha prototype was demonstrated and its different components were evaluated by means of experimental, analytical and descriptive evaluation techniques. The RDT experiment demonstrated that the web-socket based communication technology is more optimised for bi-directional data exchange protocols as compared to HTTP and Ajax based protocols. The KapCha prototype's database-centric design pattern is highly scalable and adheres to security considerations.

The interview findings revealed the fit between the tasks and the IoT model for FSA as a technology. The use of intelligent algorithms and data accessibility are features of the model identified that can aid in the reduction of downtime. The results of the evaluations revealed that the implementation of the various techniques and features of the model optimised FSA within the smart lighting environment. The implementation of the decision tree algorithm aided in the diagnosis tasks when an issue occurred. Furthermore, the implementation of a web-socket based protocol provided a low-cost data communication protocol with real-time bi-directional capabilities.

The research objective confirmed positively by this chapter was:

RO 8: Determine, by means of evaluation, whether the KapCha prototype can optimise FSA within the smart lighting environment in the case study.

It can be deduced from the evidence provided by the results of the evaluations that the KapCha prototype can optimise FSA within the smart lighting environment in the case study, by addressing the problems identified (Table 4-5). The results highlighted the following:

- The web-socket protocol implemented enabled real-time communication which supports RPC. The lack of real-time data transfer (CP-1) and the half duplex communication protocol (CP-3) problems are addressed by means of the web-socket protocol. Furthermore, the web-socket protocol has lower data transmission costs as compared to the SMS based protocol in the case study (CP-2).
- The implementation of the decision tree to automate fault diagnosis addresses the inability to diagnose problems remotely within the case study (CP-4).
- The PHP REST API implemented provides a communication interface for mobile devices to connect to the smart lighting system thereby providing a platform for mobile technologies to be used (CP-6).

Therefore, through addressing the six problems identified within the case study it is evident that the KapCha prototype can optimise FSA within the smart lighting environment in the case study.

Chapter 7. Conclusions

7.1. Introduction

The previous chapter fulfilled the fifth activity of the DSRM namely, *evaluation of artefact*. The IoT model for FSA and the KapCha prototype were evaluated and their results discussed. This chapter concludes the dissertation by reviewing the research questions and research objectives in order to determine whether the study can be considered successful (Section 7.2). The chapter fulfils the sixth activity of the DSRM methodology, *Communication* (Section 2.3.3), which is performed in the Rigor Cycle (Figure 7-1). The main research question of this research was:

How can an Internet of Things (IoT) be used to optimise field service automation (FSA)?

Similarly, the main research objective of this research was:

To develop a model for the optimisation of FSA using IoT techniques and technologies.

The DSRM was used throughout this research in the development of the theoretical and practical artefacts namely the IoT Model for FSA (Section 4.7) and the KapCha prototype (Section 5.5). The application of the DSRM activities in the fulfilment of the research objectives shall be reported on (Section 7.2). The theoretical and practical contributions of this research are highlighted (Section 7.4). During this research some problems and limitations were experienced (Section 7.4). Some of the limitations and challenges encountered highlighted future possible areas of research (Section 7.5). The full outline of the chapter is provided in Figure 7-2.

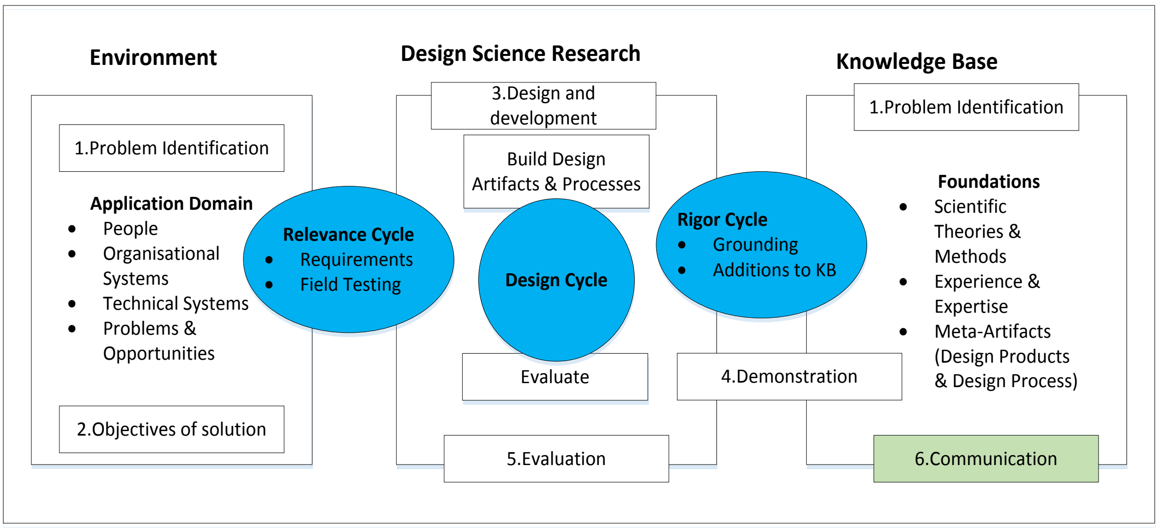

Figure 7-1 Chapter 7 Position in DSRM

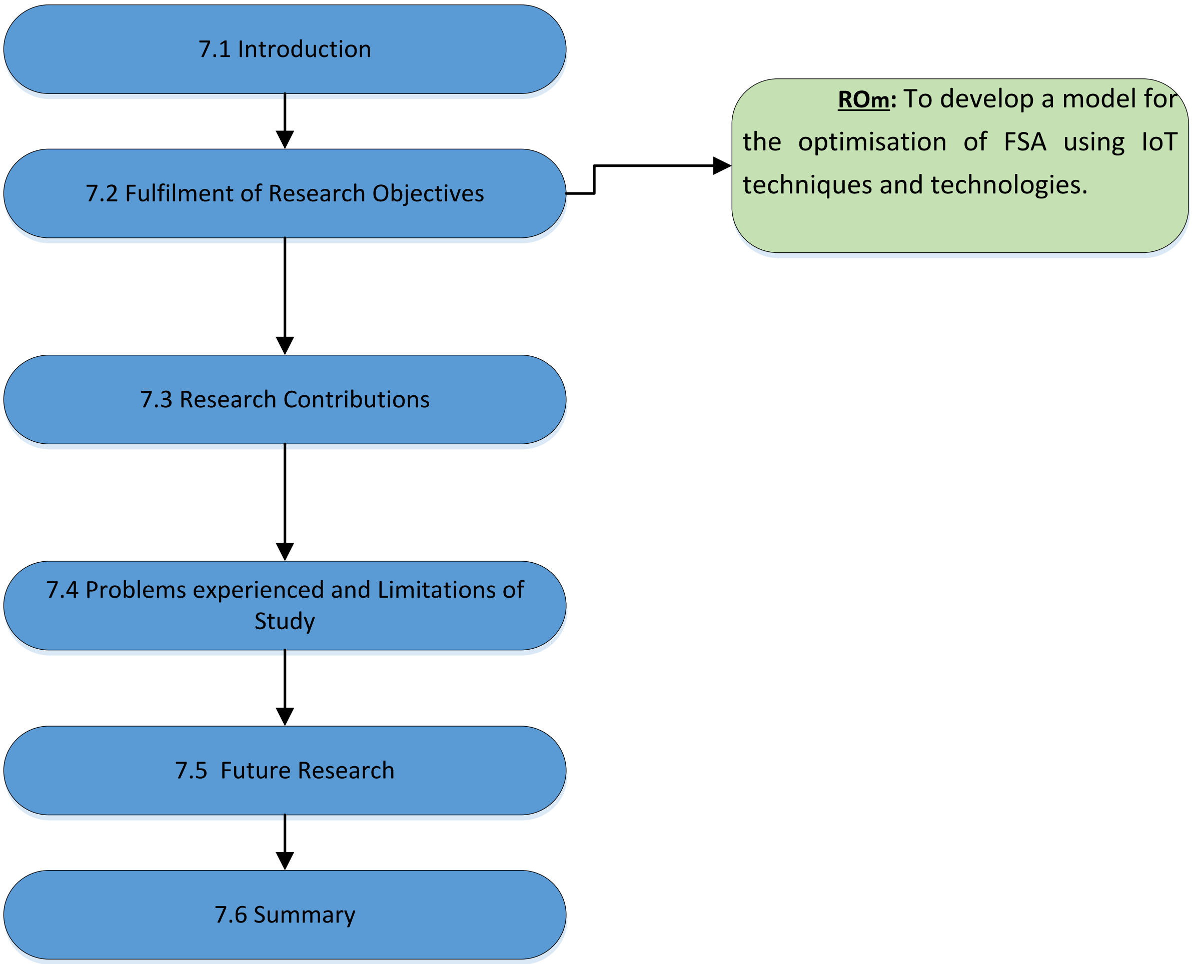

Figure 7-2 Chapter Outline

7.2. Fulfilment of Research Objectives

This research revealed that techniques and technologies of an IoT can be used to address problems faced in FSA. These problems were addressed through the proposed model. The proposed model consists of IoT technologies, architectures and components as well as techniques and functions used within the IoT ecosystem. The main research objective of this research (Section 1.6) was:

To develop a model for the optimisation of FSA using IoT techniques and technologies.

In order to fulfil the main research objective, the following sub-objectives were derived (Section 1.6):

RO 1. Identify problems faced by after sales field service organisations (Chapter 3).

RO 2. Identify the technologies that can be used to optimise FSA and technologies enabling the growth of IoT (Chapter 3).

RO 3. Identify the problems faced by an IoT (Chapter 3).

RO 4. Determine the real-world problems faced by field service organisations (Chapter 4).

RO 5. Identify the requirements and objectives of an IoT-based FSA system (Chapter 4).

RO 6. Design an IoT model to optimise FSA (Chapter 4).

RO 7. Develop of FSA system (the KapCha prototype) using the model. (Chapter 5).

RO 8. Determine, by means of evaluation, whether the KapCha prototype can optimise FSA within the smart lighting environment in the case study (Chapter 6).

The activities and guidelines of the DSRM identified (Section 2.3.3), were adhered to throughout this research. These aspects of the DSRM were used to achieve each of the research objectives identified above.

The first research objective (RO 1) of this study was to ***identify the problems faced by field service organisations***. The identification of the problems faced by after-sales field service organisations aided in defining the research problem and its justification of a solution thereby fulling the first activity of the DSRM. The problems identified consisted of three categories namely managerial, technical and market-related problems (Table 3-1). The managerial problems include the management of customer's expectations and the establishment of strategies to manage service provision for geographically dispersed clients. Technical problems identified included the lack of integration amongst enterprise systems and the inability to access equipment data in real-time. Downtime management was identified as a problem resulting from technical and managerial variables. The growth of the field services market has led to an increase in the number of service providers which resulted in the market-related problem of increase in competition.

The second research objective (RO 2) in this study was to ***identify the technologies that can be used to optimise FSA and enable the growth of IoT.*** The technologies that can be used to optimise FSA identified consist of CPS, cloud-computing and IoT (Section 3.5). From the technologies identified IoT was identified as the core technology to use to optimise FSA as it encompasses techniques from the other technologies. Big Data, cloud-computing, intelligent systems and data collection technologies were identified amongst the technologies enabling the growth of IoT (Section 3.7).

The third research objective (RO 3) in the study was to ***identify the problems faced by an IoT***. The challenges of IoT were identified as barriers that are inhibiting the full growth potential of IoT (Section 3.8). The challenges of IoT identified include security concerns, such as data confidentiality, and the management of Big Data. Another problem identified was the lack of standardisation amongst protocols, architectures and structure of an IoT. The lack of standardisation was highlighted by the difference in views of an IoT presented by researchers (Section 3.9.4).

Chapter 4 addressed, the fourth research objective (RO 4) which was to ***identify the real-world problems faced by field service organisations.*** These problems were identified by conducting interviews with industry experts within the field service industry (Section 4.3.1). The problems identified from the interview findings further aided in defining the research problem and providing justification of a solution, thereby adhering to the first activity of the DSRM. The interview findings also provided objectives of FSA system. Problems identified problems by the interview findings include the lack of end-to-end view of operations by service providers and the inadequate use of mobile technologies by service technicians (Table 4-4). The interview findings reported problems that were also identified during the literature study such as management of customer demand and expectation.

The fifth research objective (RO 5) of this research was to ***Identify the requirements and objectives of an IoT-based FSA system***. The system requirements were derived from the literature study the system analysis of existing systems and interviews (Section 4.2). The key system requirements identified address either problems of FSA or fulfil a KPI. The system requirements identified were:

- The provision of support to facilitate the data accessibility between an OEM's device/equipment and a remote service provider
- Provide low-cost and Secure data exchange protocol; and
- The use of intelligent algorithms for data analysis and task management (Table 4-6).

The sixth research objective (RO 6) in this study was to ***design an IoT model to optimise FSA***. The third activity of the DSRM was completed through the design of the model. The design of the IoT model inherited key features from the three different views of IoT to create an initial standardised comprehensive model (Figure 3-13). The features from the views included the Four-Layered Architecture and the Three-Phase Data Flow Process. The inheritance of the features from the different IoT views enabled the model to possess the benefits from each view (Section 3.9.4). The model design was also guided by the system requirements for an IoT-based FSA identified from RO 6.

The seventh research objective (RO 7) in this study was to ***develop of FSA system (the KapCha prototype) using the model.*** The development of the KapCha prototype demonstrated how to use the theoretical artefact to solve the FSA optimisation problem, thus achieving the fourth activity of the DSRM. The KapCha prototype was developed as a proof of concept to fulfil this research objective. The KapCha prototype was developed by means of incremental prototyping (Figure 5-6). Elements within the KapCha prototype adhered to the model structure as well as the system requirements of an IoT-based FSA (Section 5.4.5).

The eighth research objective (RO 8) in this study was to ***determine by means of evaluation whether the KapCha prototype can optimise FSA within the smart lighting environment in the case study***. Evaluation of the theoretical model by means of an interview and the experimental evaluations of the KapCha prototype highlighted how well the two artefacts as solutions to address the field service problems identified in activity one by comparing them to the solution objectives identified in activity two. The KapCha prototype was iteratively evaluated using the technical and risk efficacy evaluation strategy (Section 5.4). The various components of the prototype, KapCha, were evaluated using experimental evaluation methods. The purpose of the experimental evaluations was to assess the performance of the prototype in ensuring it addresses the FSA challenges identified in the case study (Table 4-5).

This section has demonstrated that all the research objectives were successfully achieved. The theoretical and practical contributions as a result of this research are highlighted in the following section.

7.3. Research Contribution

The research contributions of this research are categorised into two areas, namely theoretical and practical contributions.

7.3.1. Theoretical Contributions

The theoretical contributions of this research study are:

- The problems faced by field service organisations (Table 4-4);
- The KPIs of FSM (Table 3-2);
- Challenges of an IoT (Section 3.8);
- The system requirements for an IoT-based FSA (Table 4-6);
- An IoT model for FSA (Figure 4-10); and
- The KapCha architecture (Figure 5-5).

The problems faced by field service organisation were derived from a literature study (Section 3.2) and interviews conducted with industry experts (Section 4.3). The findings from the two research approaches identified two common types of problems, managerial and technical. The managerial problems such as the management of customer demand and expectations were reported on in both research approaches, that is the literature study and the interviews. The interview findings highlighted some additional challenges not presented in literature, such as a lack of an end-to-end a view which limits service effectiveness (Section 4.3.2).

During the design of the model, the problems of field services and the challenges of IoT were also taken into consideration. The systems requirements were derived through the fulfilment of the KPIs and by addressing the problems of FSA and IoT challenges. Therefore, the system requirements not only address the problems of FSA and challenges of IoT but also adhere to the KPIs.

The architecture of the KapCha prototype demonstrated the implementation of the model and an IoT system without the use of cloud-computing services. Cloud-computing services were highlighted as an enabling technology of IoT and FSA. However due to resource constraints these cloud-computing services could not be utilised in this research. The database-centric approach adopted by the KapCha prototype highlighted the model's generic versatility as a prescriptive solution.

The main research contribution of this research is, therefore, the theoretical prescriptive model to optimise FSA (Section Figure 4-10). The model was proposed after an analysis of literature and systems, as well as conducting interviews with industry stakeholders to identify the problems of field service delivery. The model was evaluated by an industry expert and his overall perceptions of the model were positive. The model serves as a reference model for standards and protocols for an IoT-based FSA within the after-sales industry, similar to that of the smart factory in the manufacturing industry (Section 3.10).

7.3.2. Practical Contributions

The practical contributions of this research are the KapCha prototype which can be used by Ensta in the optimisation of field services in the smart lighting environment. The KapCha prototype addresses all the problems identified from the interview findings with an engineer (P6) from the engineering consulting firm. The KapCha web-socket protocol supports bi-directional and full duplex communication between a smart light and a remote server in real-time. Furthermore, the KapCha web-socket server implements an expert system mechanism using intelligent algorithms for data analysis. The intelligent algorithm, C4.5 decision tree, automates the fault detection and provides an issue report. The use of the intelligent algorithm will be implemented in the next version of the smart lighting system within the case study to be developed by the engineering consulting firm. Furthermore, the architecture of the prototype, KapCha, developed based on the IoT for FSA model is ideal for geographically dispersed devices and clients.

The KapCha prototype was evaluated through experimental evaluations to assess the extent to which it can optimise FSA. The results of the RTD time indicated that web-sockets are more efficient that other web-based data transfer protocols such as Ajax. The results of the evaluation present the opportunity for other researchers to potentially use these results as a comparative source of reference when conducting similar research.

The KPIs of FSM are measurement metrics that aid in identifying areas within the service organisation that need to be reviewed in order to improve the organisations operations (Section 3.3). The KPIs can also be used to evaluate factors that are crucial to the success of a service organisation. Furthermore, the use of the KPIs can aid managers in making strategic business decisions.

The architecture of the KapCha system was adopted in the development of an automated integrated parking system for the disabled developed by the engineering consulting firm. The researcher was one of two participants who developed the system. The system has parking barriers, as smart objects, that communicate with a web-socket based server to manage parking availability for disabled parking bays. The innovative solution received an award at the NMMU 2016 Innovation awards. This achievement highlighted the feasibility to use the model in the development an IoT-based system.

7.4. Problems Experienced and Limitations of Study

Several problems were experienced throughout this research. One of the problems encountered was identified to be a restriction on GSM protocols offered by the mobile service provider. Mobile service providers such as MTN and Vodacom do not support the use of web-socket connections over their GSM protocols. Prior to coming to know about these restrictions the researcher spent many weeks trying to diagnose the problem. The researcher, therefore, resorted to using Cell C which proved successful however the mobile service connection was unstable.

Another problem encountered was the inability of the researcher to test the prototype in its natural environment due to legal barriers in form of inventor patents. The inventor patents on the smart lighting environment system used in the case study prohibited the researcher to perform naturalistic evaluations. Therefore, the researcher resorted to performing experiments on historical data acquired during the testing period of the system.

The study was limited in terms of scope and accessibility to smart lighting resources. The study focused on the creation of the model, however not all elements of the model could be developed due to the time and resource constraint. The inventor was not willing to have the prototype tested within the live environment. The resources of the smart lighting systems resources could not be fully accessed due to inventor patents.

7.5. Future Research

The KapCha prototype can be extended to include functionality such as predictive maintenance. Through the use of AI mechanisms models to support the prediction of faults before they occur can be developed to provide predictive maintenance functionality. Additional intelligence can be achieved by interacting with other systems in the same environment that have a direct impact on the equipment’s performance. The addition of predictive mechanisms as well as enabling object interaction with other systems will transform regular equipment into a self-aware and self-learning machines, and consequently improves overall performance and maintenance management.

7.6. Summary

This research has produced two artefacts in compliance with the DSR Guideline 1 (Table 2-2), namely:

- The IoT model for FSA (theoretical artefact); and

- The KapCha prototype (practical artefact)

The IoT model was developed as a prescriptive solution to optimise FSA as well as address FSA problems. The model consists of a Four Layered Architecture and a Three-Phase Data Process. Positive results were reported by the artificial- summative interview evaluation conducted with an expert participant.

The KapCha prototype was developed as a proof-of-concept system based on the model and was successfully evaluated. The results of the evaluation indicated that KapCha successfully achieved its requirements. The research questions and objectives were successfully answered and achieved at the end of this research study.

--The End--

References

Advice Software. (2015). ServiceMax. Retrieved March 7, 2016, from www.softwareadvice.com/za/field-service/servicemax-profile/

Agnihothri, S., Sivasubramaniam, N., & Simmons, D. (2002). Leveraging technology to improve field service. *International Journal of Service Industry Management*, *13*(1), 47–68. http://doi.org/10.1108/09564230210421155

Alazraki, D. (2015). Top 3 Field Service Challenges. Retrieved April 5, 2015, from The customer?s relationship with an organization has dramatically changed

Ashton, K. (1999). That "Internet of Things" Thing. *RFiD Journal*, 4986. Retrieved from http://www.itrco.jp/libraries/RFIDjournal-That Internet of Things Thing.pdf\npapers3://publication/uuid/8191C095-0D90-4A17-86B0-550F2F2A6745

Basu, C., Caubel, J. J., Kim, K., Cheng, E., Dhinakaran, A., Agogino, A. M., & Martin, R. A. (2014). Sensor-based predictive modeling for smart lighting in grid-integrated buildings. *IEEE Sensors Journal*, *14*(12), 4216–4229. http://doi.org/10.1109/JSEN.2014.2352331

Bauer, K. (2004). KPIs-The metrics that drive performance management. *Information Management*, *14*(9), 63. article.

Behara, R. S., & Lemmink, J. G. a. M. (1997). Benchmarking field services using a zero defects approach. *International Journal of Quality & Reliability Management*, *14*(5), 512–526. http://doi.org/10.1108/02656719710170738

Beheshti, H. M. (2006). What managers should know about ERP/ERP II. *Management Research News*, *29*(4), 184–193. http://doi.org/10.1108/01409170610665040

Belvedere, V., Grando, A., & Bielli, P. (2013). A quantitative investigation of the role of information and communication technologies in the implementation of a product-service system. *International Journal of Production Research*, *51*(2), 410–426. http://doi.org/10.1080/00207543.2011.648278

Bi, Z., Member, S., Xu, L. Da, Member, S., Wang, C., & Member, S. (2014). Internet of Things for Enterprise Systems of Modern Manufacturing, *10*(2), 1537–1546.

Borgia, E. (2014). The Internet of Things vision : Key features , applications and open issues. *Computer Communications*, *54*, 1–31. http://doi.org/10.1016/j.comcom.2014.09.008

Botta, A., De Donato, W., Persico, V., & Pescapé, A. (2016). Integration of Cloud computing and Internet of Things: A survey. *Future Generation Computer Systems*, *56*, 684–700. http://doi.org/10.1016/j.future.2015.09.021

Bray, T. (2014). The JavaScript Object Notation (JSON) Data Interchange Format. Retrieved June 14, 2016, from https://tools.ietf.org/html/rfc7159

Broll, G., Keck, S., Holleis, P., & Butz, A. (2009). Improving the accessibility of NFC/RFID-based mobile interaction through learnability and guidance. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services* (p. 37). inproceedings.

Bryman, A. (2012). *Social Research Methods*. *Social Research Methods* (4th ed.). New York: Oxford University Press Inc. Retrieved from http://books.google.co.za/books?hl=en&lr=&id=vCq5m2hPkOMC&oi=fnd&pg=PP2&dq=research+methods+&ots=CJTfNpcXpC&sig=C9Auq7bVY6G0Fl2uIlOwXZcFboA#v=onepage&q=research methods&f=false

Bucherer, E., & Uckelmann, D. (2011). Business Models for the Internet of Things. *Architecting the Internet of Things*, *15*(14), 253–277. http://doi.org/10.1007/978-3-642-19157-2

Buratti, C., Conti, A., Dardari, D., & Verdone, R. (2009). An overview on wireless sensor networks technology and evolution. *Sensors*, *9*(9), 6869–6896. article.

Buyya, R., Broberg, J., & Goscinski, A. M. (2010). *Cloud computing: Principles and paradigms* (Vol. 87). book, John Wiley & Sons.

Castro, M., Jara, A. J., & Skarmeta, A. F. G. (2013). Smart lighting solutions for smart cities. *Proceedings - 27th International Conference on Advanced Information Networking and Applications Workshops, WAINA 2013*, 1374–1379. http://doi.org/10.1109/WAINA.2013.254

Chang, Y. C., & Yen, H. R. (2012). Introduction to the special cluster on managing technology-service fusion innovation. *Technovation*, *32*(7–8), 415–418.

http://doi.org/10.1016/j.technovation.2012.04.002

Chaniotakis, I. E., Lymperopoulos, C., Rigopoulou, I. D., & Siomkos, G. I. (2008). After-sales service quality as an antecedent of customer satisfaction: The case of electronic appliances. *Managing Service Quality*, *18*(5), 512–527. http://doi.org/10.1108/09604520810898866

Chen, M., Wan, J., & Li, F. (2012). Machine-to-machine communications: Architectures, standards and applications. *KSII Transactions on Internet and Information Systems*, *6*(2), 480–497. http://doi.org/10.3837/tiis.2012.02.002

Chui, M., Loffer, M., & Roberts, R. (2010). The Internet of Things. *Mkcinsey Quaterly*. http://doi.org/10.1109/IEEESTD.2007.373646

Clicksoftware. (2015). Click Field Service Edge. Retrieved April 3, 2016, from http://www.clicksoftware.com/products/click-field-service-edge/

Coetzee, L., & Eksteen, J. (2011). The Internet of Things – Promise for the Future ? An Introduction. *IST-Africa Conference Proceedings*, 1–9. http://doi.org/ISBN:978-1-905824-24-3

De Villiers, M. R. (2005). Interpretive research models for Informatics: action research, grounded theory, and the family of design-and development research. *Alternation*, *12*(2), 10–52. Retrieved from http://alternation.ukzn.ac.za/Files/docs/12.2/02 deV.pdf

Desai, M. K. (2016). Internet of Things : Privacy & Security Issues, *3*(2), 227–230.

Dias, S., Diniz, J., & Hadjileontiadis, L. (2014). *Towards an Intelligent Learning Management System Under Blended Learning*. Lisbon: Springer International Publishing.

Envirothon, N. A., Issue, C., Objectives, L., Agriculture, S., & Grown, L. (2014). Three Pillars of Sustainability.

Fette, I. (2011). The WebSocket Protocol. *Internet Engineering Task Force, Request for Comments*, *53*(9), 1–79. http://doi.org/10.1017/CBO9781107415324.004

Fleisch, E. (2010). What is the internet of things? An economic perspective. *Economics, Management, and Financial Markets*, (2), 125–157. article.

Gaiardelli, P., Saccani, N., & Songini, L. (2007). Performance measurement of the after-sales service network-Evidence from the automotive industry. *Computers in Industry*, *58*(7), 698–708. http://doi.org/10.1016/j.compind.2007.05.008

Gartner Inc. (2015). Gartner Hype Cycle. Retrieved April 24, 2015, from http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp

Geerts, G. L. (2011). A design science research methodology and its application to accounting information systems research. *International Journal of Accounting Information Systems*, *12*(2), 142–151. http://doi.org/10.1016/j.accinf.2011.02.004

Goldman Sachs. (2014). The next industrial revolution : Moving from B-R-I-C-K-S to B-I-T-S. *Equity Research*, *3*(Cl).

Goodhue, D. L. (1998). Development and measurement validity of a task-technology fit instrument for user evaluations of information system. *Decision Sciences*, *29*(1), 105–138. article.

Green, J. (2014). The Internet of Things Reference Model. *Internet of Things World Forum*, 1–12.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, *29*(7), 1645–1660. http://doi.org/10.1016/j.future.2013.01.010

Guida, G., Lamperti, G., & Zanella, M. (2013). *Software Prototyping in Data and Knowledge Engineering* (Vol. 497). book, Springer Science & Business Media.

Hevner, A., & Chatterjee, S. (2010). Design Research in Information Systems, *22*, 9–23. http://doi.org/10.1007/978-1-4419-5653-8

Hevner, A. R. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2), 87–92.

Hevner, von A., March, S. T., Park, J., & Ram, S. (2004). Design science in information systems research. *MIS Quarterly*, *28*(1), 75–105. article.

Hinckley, K., Pierce, J., Sinclair, M., & Horvitz, E. (2000). Sensing techniques for mobile interaction. *Proceedings of the 13th Annual ACM Symposium on User Interface Software and Technology - UIST '00*, 91–100. http://doi.org/10.1145/354401.354417

Hssina, B., Merbouha, A., Ezzikouri, H., & Erritali, M. (2014). A comparative study of decision tree ID3 and C4.5. *International Journal of Advanced Computer Science and Applications*, (2), 13–19. http://doi.org/10.14569/SpecialIssue.2014.040203

HUANG, F. (2013). *Web Technologies for the Internet of Things*. Aalto University.

Intel. (2013). Getting Started with Big Data, (February).

International Energy Agency. (2015). *Energy Efficiency Market Report 2015*. Retrieved from http://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf

International Telecommunications Union. (2005). The internet of things. *ITU Internet Reports - Executive Summary*, 1–28. http://doi.org/10.1109/IEEESTD.2007.373646

Irick, M. L. (2015). Task - Technology Fit and Information Systems Effectiveness, *9*(3), 1–5.

Jazdi, N. (2014). Cyber physical systems in the context of Industry 4.0. *2014 IEEE Automation, Quality and Testing, Robotics*, 2–4. http://doi.org/10.1109/AQTR.2014.6857843

Johannesson, P., & Perjons, E. (2012). *A Design Science Primer* (1st ed.). Lexington: CreateSpace Independent Publishing Platform.

JSON. (2014). Introducing JSON. Retrieved June 14, 2016, from www.json.org

Kagermann, H., Wahlster, W., & Helbig, J. (2013). Securing the future of German manufacturing industry: Recommendations for implementing the strategic initiative INDUSTRIE 4.0. *Final Report of the Industrie 4.0 WG*, (April), 82.

Klopping, I. M., & Mckinney, E. (2004). Extending the Technology Acceptance Model and the Task-Technology Fit Model To Consumer E-Commerce. *Information Technology, Learning, and Performance Journal*, *22*(1), 35–48.

Knotts, R. M. H. (1999). Civil aircraft maintenance and support Fault diagnosis from a business perspective. *Journal of Quality in Maintenance Engineering*, *5*(4), 335–348. article.

Koh, L. H., Tan, Y. K., Wang, Z. Z., & Tseng, K. J. (2011). An energy-efficient low voltage DC grid powered smart LED lighting system. *IECON Proceedings (Industrial Electronics Conference)*, 2883–2888. http://doi.org/10.1109/IECON.2011.6119610

Kortuem, G., Kawsar, F., Fitton, D., & Sundramoorthy, V. (2010). Smart objects as building blocks for the Internet of things. *Internet Computing, IEEE*, *14*, 44–51. http://doi.org/10.1109/MIC.2009.143

Lee, E. A. (2008). Cyber physical systems: Design challenges. In *Object Oriented Real-Time Distributed Computing (ISORC), 2008 11th IEEE International Symposium on* (pp. 363–369). inproceedings.

Lee, J., Bagheri, B., & Kao, H. A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters*, *3*, 18–23. http://doi.org/10.1016/j.mfglet.2014.12.001

Lehtonen, O. (2005). *Taking Advantage of After-Sales Product Information in a Multi-company Environment*. HELSINKI UNIVERSITY OF TECHNOLOGY.

Lehtonen, O., Ala-Risku, T., & Holmström, J. (2012). Enhancing field-service delivery: the role of information. *Journal of Quality in Maintenance Engineering*, *18*(2), 125–140. http://doi.org/10.1108/13552511211244175

Lele, M. M., & Karmarkar, U. S. (1983). Good product support is smart marketing. *Harvard Business Review*, *61*(6), 124–132. article.

Lubbers, P., & Greco, F. (2010). HTML5 web sockets: A quantum leap in scalability for the web. *SOA World Magazine*. article.

McNeill, W., Maoz, M., & Wong, J. (2013). *Magic Quadrant for Field Service Management Market Definition / Description Magic Quadrant for Field Service Management*. Retrieved from http://www.gartner.com/technology/reprints.do?id=1-2405PSX&ct=141104&st=sb

McNeill, W., Maoz, M., & Wong, J. (2014). Magic Quadrant for Field Service Management. *Gartner*, (December), 1–14. Retrieved from http://www.gartner.com/technology/reprints.do?id=1-2405PSX&ct=141104&st=sb

Mell, P., & Grance, T. (2011). The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology. *National Institute of Standards and Technology, Information Technology Laboratory*, *145*, 7. http://doi.org/10.1136/emj.2010.096966

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. http://doi.org/10.1016/j.adhoc.2012.02.016

Nataliia, L., & Elena, F. (2015). Internet of Things as a Symbolic Resource of Power. *Procedia - Social and Behavioral Sciences*, *166*, 521–525. http://doi.org/10.1016/j.sbspro.2014.12.565

Newe, G. (2015). Delivering the Internet of Things. *Network Security*, *2015*(3), 18–20. http://doi.org/10.1016/S1353-4858(15)30020-9

Oberhaus, D. (2015). This Is What the Fourth Industrial Revolution Looks Like. Retrieved October 18, 2016, from http://motherboard.vice.com/read/life-after-the-fourth-industrial-revolution

Parmenter, D. (2015). *Key performance indicators: developing, implementing, and using winning KPIs*. book, John Wiley & Sons.

Peffers, K., Tuunanen, T., Rothenberger, M. a., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems*, *24*(3), 45–77. http://doi.org/10.2753/MIS0742-1222240302

Petrakis, I., Hass, C., & Bichler, M. (2012). On the impact of real-time information on field service scheduling. *Decision Support Systems*, *53*(2), 282–293. http://doi.org/10.1016/j.dss.2012.01.013

Pikkarainen, T., Pikkarainen, K., Karjaluoto, H., & Pahnila, S. (2004). Consumer acceptance of online banking: an extension of the technology acceptance model. *Internet Research*, *14*(3), 224–235. article.

Pries-Heje, J., Baskerville, R. L., & Venable, J. R. (2008). Strategies for Design Science Research Evaluation. *European Conference on Information Systems (ECIS)*, *Paper 87*, 1–13. http://doi.org/10.1177/1933719108329095

Przydatek, B., Song, D., & Perrig, A. (2003). SIA: Secure Information Aggregation in Sensor Networks. *ACM SenSys*, 255–265.

Rajkumar, R. R., Lee, I., Sha, L., & Stankovic, J. (2010). Cyber-physical systems: the next computing revolution. In *Proceedings of the 47th Design Automation Conference* (pp. 731–736). inproceedings.

Rotter, J. (2016). Top Field Service KPIs in 2016 and Pro Tips to Help Service Managers Meet Them. *MSI Data*. Retrieved from http://www.msidata.com/field-service-kpis-and-pro-tips-michael-israel-interview

Salesforce. (2015). Field Service Lightning. Retrieved February 1, 2016, from http://www.salesforce.com/eu/service-cloud/features/field-service-lightning/

Sarkar, S. S. (2015). The Challenges in Field Service Management. Retrieved April 1, 2015, from http://www.rapidvaluesolutions.com/the-challenges-in-field-service-management/

Sathya, R., & Abraham, A. (2013). Comparison of Supervised and Unsupervised Learning Algorithms for Pattern Classification. *International Journal of Advanced Research in Artificial Intelligence*, *2*(2), 34–38. http://doi.org/10.14569/IJARAI.2013.020206

Saunders, M., Lewis, P., & Thornhill, A. (2007). *Research methods for business students*. book, Pearson Education UK.

Saunders, M. N. K., Saunders, M., Lewis, P., & Thornhill, A. (2011). *Research methods for business students, 5/e*. book, Pearson Education India.

Schneider, J., Gaul, A. J., Neumann, C., Hogräfer, J., Wellßow, W., Schwan, M., & Schnettler, A. (2006). Asset management techniques. *International Journal of Electrical Power & Energy Systems*, *28*(9), 643–654. article.

Schofield, K. (2014). Making S-E-N-S-E of the next mega-trend, *1*, 1–57.

Stevenson, A. (2010). *Oxford dictionary of English*. book, Oxford University Press.

Stutz, B. (2015). Microsoft acquires FieldOne, global provider of field service management solutions for the enterprise. Retrieved March 27, 2016, from https://blogs.microsoft.com/blog/2015/07/16/microsoft-acquires-fieldone-global-provider-of-field-service-management-solutions-for-the-enterprise/#sm.000vpohiu1ccxdp5s5n25k1vr5plc

Szekely, P. (1995). User Interface Prototyping : Tools and Techniques. *Software Engineering and Human-Computer Interaction*, *896*, 76–92.

Tan, P.-N., Steinbach, M., & Kumar, V. (2006). Classification : Basic Concepts , Decision Trees , and. *Introduction to Data Mining*, *67*(17), 145–205. http://doi.org/10.1016/0022-4405(81)90007-8

Thwink.org. (2011). Model. Retrieved November 24, 2016, from http://www.thwink.org/sustain/glossary/Model.htm

Turban, E., Volonino, L., McLean, E., & Wetherbe, J. (2010). *Information Technology for management: Transforming organisations in the digital economy*. Asia: Wiley & Sons.

Vaishnavi, V. K., & Kuechler, W. (2015). *Design science research methods and patterns: innovating information and communication technology*. book, CRC Press.

Vans, A. M., von Mayrhauser, A., & Somlo, G. (1999). Program understanding behavior during corrective maintenance of large-scale software. *International Journal of Human-Computer Studies*, *51*(1), 31–70. article.

Venable, J., Pries-heje, J., & Baskerville, R. (2014). FEDS: a Framework for Evaluation in Design Science Research. *European Journal of Information Systems*, *25*(October 2012), 1–13. http://doi.org/10.1007/978-3-642-29863-9_31

Vinay, A., & Boulanger, R. (2016). Building Interactive Systems with WebSockets and Csound! article.

Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D. (2015). Towards industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, *48*(3), 579–584. http://doi.org/10.1016/j.ifacol.2015.06.143

Williams, C. R. (1998). Preventative maintenance and diagonstic system. misc, Google Patents.

Xu, Z., Ming, X. G., Zheng, M., Li, M., He, L., & Song, W. (2014). Cross-trained workers scheduling for field service using improved NSGA-II. *International Journal of Production Research*, *53*(4), 1255–1272. http://doi.org/10.1080/00207543.2014.955923

Xu, L. Da, He, W., & Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics*, *10*(4), 2233–2243. http://doi.org/10.1109/TII.2014.2300753

Yu, Z., & Wang, T. N. (2012). Research on the visualization of equipment support based on the technology of Internet of Things. *Proceedings of the 2012 2nd International Conference on Instrumentation and Measurement, Computer, Communication and Control, IMCCC 2012*, 1352–1357. http://doi.org/10.1109/IMCCC.2012.318

Zheng, J., & Jamalipour, A. (2009). *Wireless sensor networks: a networking perspective*. book, John Wiley & Sons.

Appendix A

Nelson Mandela Metropolitan University

for tomorrow

Faculty RTI Committee (Faculty of Science)
Tel: +27 (0) 41 5042268
E-mail: lynette.roodt@nmmu.ac.za

Ref: **H15-SCI-CSS-011**
Dr B Scholtz

Contact person: Mrs L Roodt

Date: 17 November 2015

Dear MM Kapeso (210000112)

TITLE OF PROJECT: Optimisation Techniques for Field Service Automation using an Internet of Things

Your above-entitled application was considered and approved by the Sub-Committee for Ethics in the Faculty of Science on 6 November 2015.

The Ethics clearance reference number is **H15-SCI-CSS-011**, and is valid for three years. Please inform the Committee, via your faculty officer, if any changes (particularly in the methodology) occur during this time.

An annual affirmation to the effect that the protocols in use are still those, for which approval was granted, will be required from you. You will be reminded timeously of this responsibility, and will receive the necessary documentation well in advance of any deadline.

We wish you well with the project. Please inform your co-investigators of the outcome, and convey our best wishes.

Yours sincerely

Lynette Roodt
Manager: Faculty Administrator
Faculty of Science

Appendix B

Meeting Minutes: Interview for the identification of FSM problems

November 14, 2016

Present: Participant P2, Mr Mando Kapeso

1. Purpose of interview

a) To establish the interviewee's (the manager or director giving supervision to the technicians) understanding of field services based on experience with field technicians.

b) To identify problems encountered toward automation and management of field services, given the purpose of the research is to optimize process of field services using the 'Internet of Things' concept that encourages machine-to-machine communication.

2. Discussion

a) Name of field service automation tool used?

Building Management System

b) What specialization is provided by the tool?

The tool specializes in electrical and mechanical equipment within remote facilities. It assists in managing a large number of buildings, a group of buildings or remotely located buildings.

c) Is there any specialization in the tasks performed by the system? Beyond repairs, maintenance, monitoring?

Gives real time data of operational capacity of the equipment.

d) How many field technicians are employed by NMMU?

Regarding the Building Management System, the technicians are outsourced, performing maintenance once a month for 22 hours a month – checking and servicing all field devices. A Plan Maintenance Schedule with outside contractor carrying out maintenance and repairs.

The university has some technicians of their own – electricians, air conditioner technicians. A total of 27 including technicians and artisans.

e) Do the technicians/artisans have any form of interaction with the Building Management System?

No interaction with the system, only attending to faults and failures. Interaction is only facilitated through communication by the supervisor/manager or the front administration office which has access to the Building Management System.

f) Any problems around information access or delivery of field services?

Lack of historical data to determine root causes of equipment failure is a challenges we are currently experiencing. Computer Maintenance Management System (CMMS) lacks customisation to be able to track historical data.

g) What additional functionality would ideally make your work easier?

All job cards and preventative maintenance schedules to be sent to the field device of the artisan. They should be able to see the history of the equipment when servicing it. To establish what maintenance or repairs have been performed. This will allow for the preventative maintenance system to establish the useful life of the equipment to assist it lowering of costs.

Thus, to develop artificial intelligence working on top of the system to facilitate a number of tasks that would require many people to accomplish – such as data analysis.

h) How much depth of information should be provided to the technician/artisan by the system?

The data should be related to the specific equipment, and should be able to receive the preventative management schedule which is to be automatically updated based on the work performed on the equipment.

i) Should the job cards be linked to the purchasing and accounting system? To request for quotes based on the repairs required?

It would be ideal, however the current university system, ITS, is suited for the university environment. A maintenance module that can, however, be purchased but it would also require customization to allow for the integration – further increasing the costs. An ERP system would be more suitable, such as SAP.

3. Proposed summary of the model

In the event a failure of some sort occurs, for example a broken belt, the smart device with sensors picks up the failure via a controller that monitors the status of the equipment. A diagnostic test is carried out trying to establish the cause of failure by trouble shooting. Artificial intelligence is then used to determine the possible causes, the probability of each possible cause, and the solutions to the problems. Based on the issue, the best solution is determined. A rule-based system is then implemented, to notify the suitable technician based on the problem identified.

Using low-end devices, service technicians can use a cross-platform app that gives information on the problem and history of the equipment. Added, the app will allow the manager to identify the technician attending to the problem.

Appendix C

Interview Minutes: NMMU

November 14, 2016

Present: Participant P2, Mr Mando Kapeso

4. Introduction

A follow-up meeting to demonstrate the developed model that meets the constructed research questions based on studied literature review. The developed model is ideal for the optimisation for Field Service Automation. The model takes concepts and looks at a vertical integration of a system, from the basic equipment to the communication protocol of sending data across, and processing of the data to an application that will have users. Example users are a dispatcher/management and service technicians with access to the system through a mobile application and/or a web portal.

Purpose of the meeting

To attain a high level opinion to contribute to the evaluation of the model, as Mr Peter Peters is an expert user within the Field Service Automation domain. Participant P2 holds the position of being a manager in an existing organisation - NMMU.

5. Discussion

The following questions were answered after a review of the model against the established requirements.

High-level questions

a) Does the model meet the expected requirements of a FSA system (have all design considerations been met)?

   Yes.

b) What are the positive features of the model?

   It is a practical model especially for industry, as they are already using automation devices to feedback to the offices. It assists with the resource scarcity in terms of human and intellectual capital. With limited skilled technicians, the model allows for semi-skilled technicians to be deployed to attend to the issue with the assistance of the intelligence provided.

c) What are the short comings or negative features of the model?

   Due to the intelligence of the model equipping the artisan with the knowledge of an issue prior the visit to the equipment – the implementation thereof will be expensive because being able to feedback that type of intelligence will require monitoring of many aspects on the equipment.

d) Is the user of the opinion that developing a system from the model is feasible?

   The model is beneficial for the investment cost if it is used for remote sites by speeding up the remedial process. However, it might not be feasible for an organisation such as NMMU, where all the equipment sites are within close proximity, although it would speed up the turnaround time.

e) What suggestions, if any, can you provide to improve the model?

The model would require the availability of scarce resources, where every artisan has access to mobile devices. This would be more beneficial if it is utilised by artisans instead of having only management involved. The model should allow for managers to have direct communication with artisans as they are in the field working onsite. Thereby allowing mangers or supervisors to provide expert advice or assist in decision making. For instance, have a live chat room session during the execution of a repair task.

FSA tasks related questions

– Maintenance tasks

a) Do you believe this model would allow maintenance users to gain data within a reasonable time frame through the suggested protocols and access to OEM's?

Yes.

b) Do you believe this model would facilitate for access to data that the maintenance user needs?

Definitely, it also assists with procurement to determine which brand would yield the longest lifespan, and which brands to avoid altogether.

– Repairs tasks

a) Do you believe this model would allow repair users to get data quickly through the suggested protocols and access to OEM's?

Yes.

b) Do you believe this model would facilitate for access to data that the repairs user needs?

Yes, the information provided would be relevant.

c) Would the model reduce downtime through the reduction in onsite time through the use of AI?

Yes, it will result in the reduction of downtime.

d) Would the model reduce downtime through reduction in onsite time?

Yes, it would reduce the root-cause analysis time and assist in identifying and reviewing of repeat faults.

Appendix D

Online Consent Form

Consent Form

Research Project : An IoT Model for FSA
Principal investigator : Mando M Kapeso (mando.kapeso@nmmu.ac.za)

* Required

Declaration By or On Behalf of the participant

1.1. I,the participant (full name) *

2. Hereby confirm as follows

2.1. I, the participant, was invited to participate in the above-mentioned research project that is being undertaken by Mando Kapeso from the Department of Computing Sciences of the Nelson Mandela Metropolitan University. *

- Agree
- Disagree

3. The following aspects have been explained to me

3.1. Aim: The primary goal of this research is to investigate the optimisation of FSA using IoT techniques. This study seeks to identify the challenges faced by field service organisations and the current techniques that are used in field service industry. The understanding of the challenges faced and current techniques used will potentially address the problem of operational optimisation faced by field service organisations *

- Agree
- Disagree

3.2. Confidentiality: My identity will not be revealed in any discussion, description or scientific publications by the investigators. *

- Agree
- Disagree

3.3. Access to findings: Any new information or benefit that develops during the course of the study will be shared as follows: published in papers and treatise *

- Agree
- Disagree

3.4. Voluntary participation / refusal / discontinuation: My participation is voluntary *

- Agree
- Disagree

3.5. Voluntary participation / refusal / discontinuation: My decision whether or not to participate will in no way affect my present or future career/employment/lifestyle. *

- Agree
- Disagree

3.6. No pressure was exerted on me to consent to participate and I understand that I may withdraw at any stage without penalisation. *

- Agree
- Disagree

3.7. Participation in this study will not result in any additional cost to myself *

- Agree
- Disagree

4. Consent

4.1. I hereby voluntarily consent to participate in the above-mentioned project. *

- Agree
- Disagree

Submit