STELLENBOSCH UNIVERSITY

The Application of Production-related Information Technology Architecture to Improve on Visual Management Systems within the Manufacturing Industry

by

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Thesis presented in fulfilment of the requirements for the degree of Master of Engineering (Industrial Engineering) in the Faculty of Engineering at Stellenbosch University

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ABSTRACT

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This research investigates the relationship between technology advancements and the effects thereof in manufacturing industry in relation to the complexity of the production lines, resource efficiency and time management. Specifically, the study focuses on the use of Production-Related Information Technology Architecture (PRITA) to improve data sourcing, processing and communication within the manufacturing environment in order to improve the use of Visual Management System (VMS) capabilities. Current technologic advancements, and therefore the manufacturing paradigm by extension, have advanced enough to make VMS a possibility. Case studies were developed and implemented with the aim of identifying the elements of VMS that facilitate data sourcing and processing in order to yield production-related information after which the information was displayed digitally. These case studies were implemented within the academic manufacturing environment that replicates typical small medium enterprises (SMEs) in South Africa. The results revealed that the VMS was considered an important value-adding element to the manufacturing industry with 77% of the expert interview participants agreeing. VMS provided the functionalities of trend analytics that could provide information regarding the operational condition of production and making conservative predictions of the production cycle analysis. VMS can provide the solution to understanding and relating the information to improve on the traditional flow of information. This new method will involve an increased amount of data collection on lower operation levels from which the information can flow up through managerial levels to produce action items and information flowing down the model again. The study concluded with an effect and benefit summery of the PRITA and VMS model, a cost and labour analysis and a discussion of research limitations.

OPSOMMING

Die toepassing van Produksieverwante Inligtingstegnologie Argitektuur om Visuele Bestuur Sisteem binne die Vervaardigingsbedryf te verbeter

Deur Lukas Petrus Steenkamp

Hierdie navorsing ondersoek die verwantskap tussen tegnologiese vooruitgang en die gevolge daarvan in die vervaardiging industrie en fokus op die kompleksiteit van die produksie lyne, doeltreffendheid hulpbron- en tydsbestuur. Die studie fokus spesifiek op die gebruik van Produksieverwante Inligtingstegnologie Argitektuur (PVITA) sisteme om data van die bron te kry, te verwerk en kommunikasie van inligting te verbeter binne die vervaardiging omgewing deur gebruik te maak van Visuele Bestuur Sisteem (VBS). Die vooruitgang van huidiglike tegnologie en dus die vervaardiging paradigma by uitbreiding, het genoeg ontwikkel die laaste tyd om VBS 'n moontlikheid te maak. Data versameling en verwerking wat deur elemente van die VBS gefasiliteer en evalueer word, wat produksieverwante inligting digitaal vertoon, is deur middel van die ontwikkeling van gevallestudies gedoen. Die gevallestudies is geïmplementeer in die akademiese vervaardigingsomgewing wat tipiese klein medium ondernemings (KMO) in Suid-Afrika verteenwoordig. Die gevolgtrekking van die navorsing is dat VBS ʼn belangrike waardetoevoeging element van die vervaardigingsbedryf is, waarvan 77% van die deskundige onderhoude deelnemers saamstem. VBS kon tendens analise wat inligting met betrekking tot die operasionele toestand van die produksie kondisie en maak konserwatiewe voorspellings van die produksiesiklus ontleding voorsien. VBS kan die oplossing bied vir die verstaan en interpretasie van inligting asook beter kommunikasie verbeter tussen organisasie vlakke. Die tradisionele inligting vloei kan verbeter word deur 'n groot data hoeveelheid insameling op laer operasie vlakke. Die moderne metode behels die vloei van inligting opwaarts deur bestuursvlakke. Die voorlaaste deel van die navorsingstudie bepreek die effek en voordele opsomming van die PVITA en VBS model, ʼn koste en arbeid ontleding en is gevolg deur beperkings wat deur die verloop van die studie ervaar is.

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously, in its entirety or in part, submitted it for obtaining any qualification.

Date: March 2017

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DEDICATION

To the future of intelligent design.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CPPS	Cyber Physical Productions Systems
CPS	Cyber-Physical Systems
DL	Deep Learning
ERP	Enterprise Resource Planning
HMS	Holonic Manufacturing Systems
HRPMS	High Resolution Production Management System
IAT	Institute for Advanced Tooling
ICT	Information and Communication Technologies
IMS	Intelligent Manufacturing Systems
IoT	Internet of Things
KPI	Key Performance Indicator
LF	Learning Factory
M2M	Machine to Machine
MES	Manufacturing Execution System
NFC	Near-Field Communication
OEE	Overall Equipment Effectiveness
PLC	Programmable Logic Controller

PRITA	Production-Related Information Technology Architecture
R&D	Research and Development
RFID	Radio-Frequency Identification
RMS	Reconfigurable Manufacturing System
RPD	Rapid Product Development
SF	Smart Factory
SLF	Stellenbosch Learning Factory
SOS	Service-Orientated Structure
STC-LAM	Stellenbosch Technology Centre - Laboratory for Advanced Manufacturing
VMS	Visual Management System

Chapter 1. INTRODUCTION

This chapter introduces the background and motivations to this research, as well its scope and scientific method employed. Additionally, the research goal, question and objectives are stipulated and the research design and methodology proposed.

1.1 BACKGROUND AND MOTIVATION

Currently, academia and industry alike are waiting in anticipation to see what will be happening in the next decade. They anticipate that the current advancement in processing power, internet speed and changing business models might change current manufacturing methods. To introduce the reader to why this is currently happening, the history of technological advancements and its influence on manufacturing paradigms, over the last three centuries, is discussed.

According to literature, the previous three notable industrial revolutions were triggered by the evolution of technology [1]–[4]. The three technology advancements in question are the invention of steam powered mechanical actions in 1784, the invention of the electrical motor in 1870 and the invention of programmable logic controllers for automation purposes in 1969 [1]–[4]. These three technology advancements were able to increase the complexity of production processes within manufacturing industry and were, therefore, responsible for producing the next production paradigm. The three production paradigms were characterised by an increase in production productivity and each of them followed a technology advancement [5], [6]. They were craft production in 1850, then mass production in 1913 and followed by flexible production paradigm in 1970 [5], [6]. Now, when looking at the current technology advancements within the information age that led to the invention of the internet, then the question becomes: are the next production paradigm to follow this?

Industry 4.0 is the German principle in which it is predicted that future industries would all work together as smart services. As such, all the data of the clients will form data-driven business models and will be stored within an information network [1]–[4]. Industry 4.0 suggests that the internet of things (IoT), which consists of millions of clients, devices and organisations connected with each other over the internet, will create a shared information space and indicate the start of this new speculated 'sharing manufacturing' production paradigm [5], [6]. As such, Industry 4.0 has been referred to as the 'fourth industrial revolution' and coincides with other technology advancements of the past. This background serves as the introduction of this study.

1.2 Problem Statement

The future of manufacturing will be greatly influenced by the attitude that industries adopt towards resource management. Maximum profit with minimum capital investment was generally accepted above the more modern approach of maximum value creation with minimum resource consumption until recently [5]–[7]. Manufacturers of the future should, therefore, be focused on the consumer's needs and value creation niches within production [5], [7]–[9]. As a result, industries can be forced to have shorter innovation cycles and complex production processes to stay competitive [10]. The importance of this new attitude becomes evident with the emerging popularity of how valuable real-time and accurate information is becoming [11], [12]. Accurate and immediate information that gets sourced from the value chain, can help to promote and improve control and performance within the complexity of the new production environment and focus can shift to increasing production efficiency whilst reducing expenses [9], [10], [13], [14].

In the South African context of this problem, the focus needs to shift to how productivity levels of low skilled workers can be increased using simple and easy understanding information communication techniques. South Africa, with its low technology maturity and limited funding, serves as a candidate for research and development in the field of visual stimuli to convey information more effectively to the workforce within the manufacturing industry. The goal is to increase productivity levels of production operations and investigate further opportunities for companies to incorporate visualization techniques [15].

The question can then be asked: how is this information being perceived by the users, customers, workers, maintenance staff or management? Literature suggests that if you take the five senses and draw a comparison, taste accounts for 1%, touch for 2%, smell for 3%, hearing for 11% and sight for an astounding 83% of all information that is collected by a person [16]–[20]. This fact leads to the next exploratory question: can a visual management system of sorts be developed to relay information to its users in a quick and easily comprehendible fashion? Finding the answers to this questions within the manufacturing industry will be the core concept of this research.

With regard to the preceding discussion, a study into the implementation and application methodology of a visual management system (VMS) is conducted within the manufacturing industry. Such a study would serve two purposes: firstly, it would serve as an access point to investigate means of data sourcing and information processing within the manufacturing industry; secondly, it could be used to enhance resource management techniques through the use of digital visual management tools [2], [13].

The goal of this study is to investigate the role that effective communication of information can play in improving production efficiency in order to develop production-related information technology architecture (PRITA) within a manufacturing environment and highlight the beneficial effects of a VMS. Such an understanding is necessary as IoT and related technologies expand into the manufacturing industry and information sourcing, processing and analysing in more precise production process analytics become an important aspect of the future production paradigm [21], [22].

1.3 Research Question

This study is guided by the following research question: What are the effects and benefits of applying production-related information technology architecture (PRITA) to produce a visual management system (VMS) within the manufacturing industry?

1.4 Research Objectives

In order to respond to the research question and meet the goal of this study, the following objectives were formulated:

1. To investigate and define VMS with the aim of developing a model for effective information communication.
2. To define elements of PRITA systems that meet the prerequisites for VMS.
3. To develop case studies that investigate and validate the implementation capabilities of the developed PRITA and VMS model.
4. To determine the influential or beneficial factors of VMS.

Here, the main problem is broken down into smaller tasks that collectively support the solution to the problem presented in the research question. These smaller tasks together make the task of answering the research question more manageable. The study objectives give pointers to the research design and methods adopted in a study.

1.5 Research Design and Methodology

The longitudinal research design will be employed in this research. This research design involves mapping change and processes that are responsible for creating change in organisations. In so doing, the design reveals social change and improves the understanding of casual influences over time [23], [24]. A longitudinal method, called a panel study, provides the platform of conducting the research that includes respondent sample groups consisting of individuals and/or organisation [24]. What follows is a list of case studies that was used in similar research:

1. Intrafirm mobility and manufacturing modernization by Ettlie (1990) [25]
2. Longitudinal Field Research on Change: Theory and Practice by Pettingrew (1995) [23]
3. Impact of work teams on manufacturing performance: A longitudinal field study by Banker et al. (1996) [26]
4. Theoretical extension of the Technology Acceptance Model: Four longitudinal field studies by Venkatesh (2000) [27]
5. Outcomes and success factors of enterprise IT architecture management: empirical insight from the international financial services industry by Schmidt and Buxmann (2010) [28]
6. VIRTUE: A visual tool for information retrieval performance evaluation and failure analysis by Angelini et al. (2014) [29]
7. Research Directions for the Internet of Things by Stankovic (2014) [30]

These case studies investigated the scope of the problem and determined solutions based on their investigatory principles. The validation process of the longitudinal research design details the method that involves capturing two sets of data on the same variable, on the same sample group. The researcher can address the potentially independent variables at the first data set and, therefore, be in a better position to infer effect of the independent variables after the second data set is captured [24].

1.6 CONCLUSION

The effects of VMS needs investigation within a manufacturing industry that supports PRITA. Case studies that investigates the elements of VMS and facilitated data sourcing, data processing in order to yield production-related information and display information digitally needs developing to support the specific objectives. The next chapter provides an in-depth discussion of the literature reviewed in relation to the topic under investigation.

Chapter 2. LITERATURE STUDY

2.1 OVERVIEW

The literature study is divided into four sections. The first section discusses the changes in production and business models arising from the advancements in technology and is entitled 'Future Production Paradigms'. The second section discusses production systems that have since been going through research and development and the section is entitled 'Current and Future Technology Advancements'. The third section explores the production-related information technology architecture (PRITA) that could be implemented within the manufacturing industry to support new information sourcing and processing technology. This fourth section is, specifically, dedicated to visual management systems (VMS) and case studies are discussed in different fields as an introduction to VMS within manufacturing. As a background to the chapter, the manufacturing industry of South Africa is first discussed in terms of performance and shortcomings.

2.2 MANUFACTURING IN SOUTH AFRICA

Manufacturing is one of the main industries in South Africa contributing approximately 17% of the national Gross Domestic Product (GDP) each year [31], [32]. While the manufacturing industry shows growth potential, the low skill level of workers, and the unreliable electricity supply may eventually make this industry become less economical in the future [8], [31], [33]. The lack of proper management as well as the unsystematic approach within South Africa's manufacturing industries results in products being delivered to clients with a delay [34]–[36]. In a comparative study of South Africa and Germany's manufacturing industries, the following became apparent: South Africa's labour is half as expensive when compared to Germany, but Germany's workers are higher skilled and therefore three times as productive [37], [38]. Consequently, the opportunity to investigate ways to improve on South Africa's productivity levels in a low funded and low skilled environment arises.

2.3 Future Production Paradigms

2.3.1 *Industry 4.0*

According to literature, the industrial revolutions are characterised by an increase in technology and/or complexity in the production environment [39]. In this quick overview, the reader should find some consistencies with what is mentioned in the introduction chapter.

The first industrial revolution started in the year 1784 with the invention of a mechanical piston-driven, steam-powered weaving loom. The second industrial revolution was characterised by mass production and made possible by the invention of the electric motor in the year 1870. The third revolution was characterised by programmable technology being incorporated for automation and control purposes in 1969 and is still being perfected to this day [2], [4], [12], [40], [41].

The fourth industrial revolution is being driven by the advancements of the information age [42] where the information of the client can be collected, which may better define the client's habits and needs. Consequently, this information is used to produce better products and services. One significant future development of Industry 4.0 is the introduction of smart services. The smart service vision builds on from the concept of combining application fields to create a universal data-driven business model. This smart service model is being tested in the logistics services in Germany's private transport sector with great success [3]. Industry 4.0 is technical and will particularly change the organisational structure of companies significantly [39]. Industry 4.0's vision is to create smart services in which manufacturing would fit together with insurance, retail, manufacturing and banking. The collection of data will enable new industries to invest their resources in creating better products and improving services throughout the entire value stream [1], [4], [13], [17], [41]. Although Industry 4.0 is only in its infancy stage, some strategies have been discussed for future development [39], [43], [44].

2.3.2 *Data-Driven Business Models*

The overlap of data that is generated by these smart services and related industrial activities such as manufacturing is displayed in Figure 2-1. The industrial data space will provide the necessary platform for collaboration within and between manufacturing industries. This new industrial data space will provide the platform for collaboration and mutual gain [45].

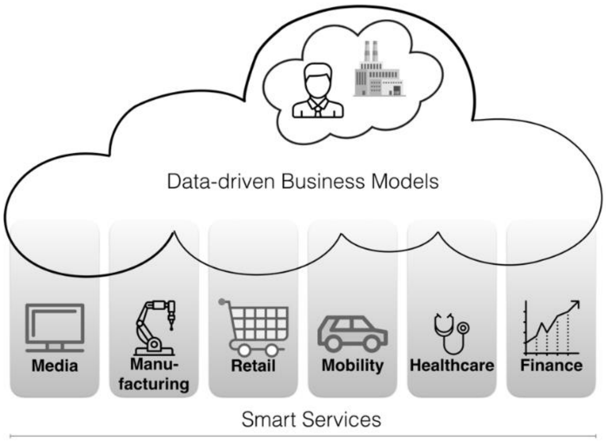


Figure 2-1: Data-Driven Business Model adopted from Acatech 2015 [3]

Machines and production equipment can now share their operating conditions and their current state in production. However, Industry 4.0 will stretch far beyond the manufacturing floor. As such, Industry 4.0 wants to create factories that are self-sustaining [22], that is, factories in which the product communicates to the equipment in the production line so that they can mutually create the best setup for the rest of the production line. These are referred to as smart factories. For a factory to be classified as a smart factory, every piece of equipment within it must have some degree of processing and communication abilities built onto it that's capable of communicating its operational state [22]. In effect, the processing power of a factory is distributed into every piece of factory equipment. When this happens, each piece of equipment knows its maintenance schedule and is able to notify the operators if there is a need for early repairs or replacements. Products of a SF are able to indicate to the production line their variant so that the smart factory can update the layout for optimal production [22], [40]. Additionally, raw material or semi-finished production material requests are made just prior to demand in a smart factory. Also, the production system is able to order the material or parts automatically from its suppliers as needed, thus, making it self-sustaining [46].

2.3.3 *Industry 4.0 and the Production Paradigms*

The focus point of this research will be to investigate how people perceive information and then react to it. According to literature, 83% of information is gathered using the sight when compared to the other four senses [16]–[20]. For this reason, visual stimuli and visual tools were investigated as future elementary applications within the manufacturing industry. The new production paradigm transformation, as displayed in Figure 2-2, will evolve from mass-production into an increasingly flexible production paradigm and eventually a production paradigm called social manufacturing as predicted by Ras (2016) and Koren et al (2010) [5], [6].

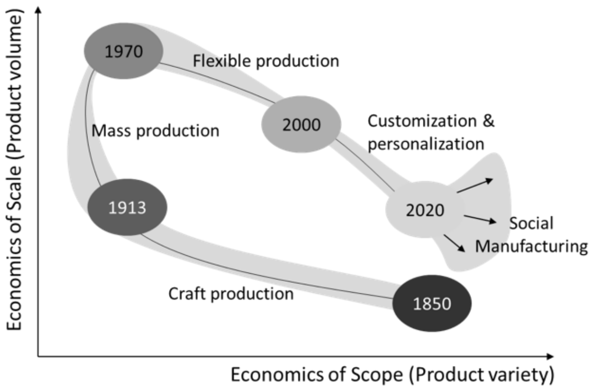


Figure 2-2: Production Paradigm compiled from Ras (2016) and Koren (2010) [5], [6]

In order to fulfil the specific needs of the customer, manufacturers have to shift their focus to customisation and personalisation, as these requirements are becoming increasingly influential factors. Manufacturing will, therefore, need a change in mind-set. The focus of the future will be on maximising the value of the products that is being created [5]–[7]. As a result, industries will be forced to have shorter innovation cycles and, as a consequence, complex production processes [7], [14].

In the section that follows, the correlation between Industry 4.0 and the production paradigms changes are discussed in order to determine the relationship between them. These were mentioned briefly in the introduction and background section, but the chronology of this relationship is addressed with an illustration and can be seen in Figure 2-3.

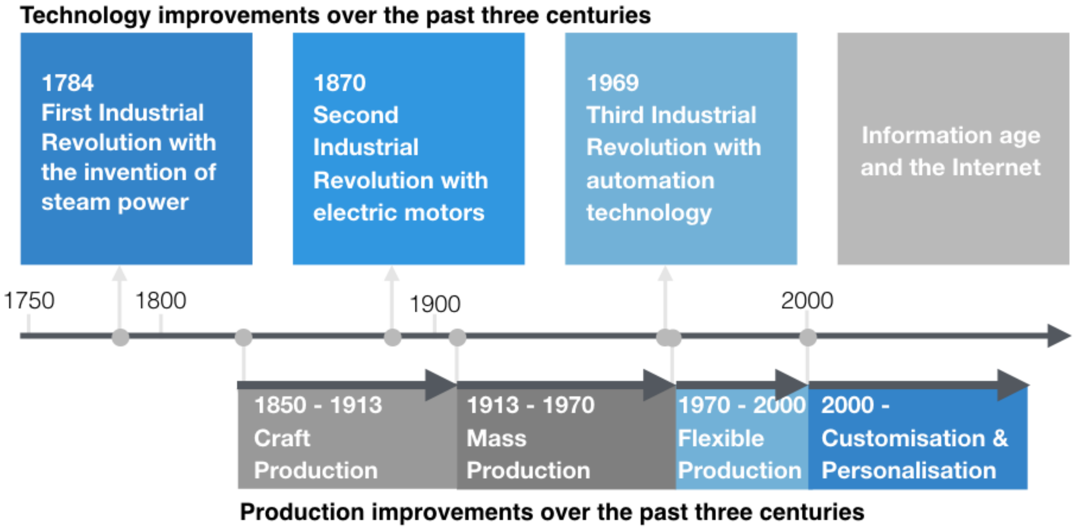


Figure 2-3: Chronology of Industry 4.0 and Production Paradigm

In the timeline, the relationship between technology advancement and the trailing production paradigm change can be observed. In the year 1784, the first steam powered loom is invented [1]–[4]. This device made fabric using a simple mechanical action powered by boiling water to drive pistons, and led to craft production paradigm being introduced within manufacturing. Craft production is the process of manufacturing by hand without the use of complicated tools or machinery to deliver unique products and span over 60 years according to literature [5], [6].

During that time, the next technological advancement was introduced. In 1870, with the invention of the electric motor, the next production paradigm was to be presented: mass production. This new production paradigm was also called the ‘flow production’ or ‘continuous production’ and was characterised by large amounts of standardized products being manufactured on an assembly line [5], [6]. The assembly line was made possible by the electric motor to drive the production line forward [1]–[4]. Along the assembly line, the shop floor workers had minor assembling tasks to produce the final product. This production paradigm stretched over 57 years.

In this time, specifically in 1969, the third technology advancement was developed, which introduced programmable logic controllers (PLC) to the manufacturing industry [1]–[4]. This led to automation within production and paved the way to the next production paradigm: flexible manufacturing [5], [6]. This production paradigm allows for some flexibility and can react to changes, whether predicted or unpredicted. This paradigm has been in use since 1970 and is currently on the verge of re-invention. For this reason, people in both the realms of academia and industry are so excited. The new production paradigm for the next few decades will incorporate the internet and information age to form an information network [3], [4]. This is due to the new technological advancements in data sourcing, clustering and processing done using both the internet and cloud computation.

New technology advancements should, therefore, change both the production paradigm and the current traditional manufacturing industry. In order for manufacturers to adapt, information handling and sourcing need to be revolutionized accordingly. Mobile technologies together with Cyber-Physical Production Systems (CPPS) will significantly increase manufacturers data collection and processing capacity. The use of information technology (IT) architectural frameworks with the objective of combining these elements, therefore, need to be introduced into the production environment. Factoring in human and machine interaction environments, collaboration of these elements can be achieved in the future with the use of technology that can effect overall improved control and production transparency [10], [14].

2.4 Current and Future Technology Advancements within the Manufacturing Industry

2.4.1 *Learning Factory*

Learning Factories (LF) are an education tool that is used to simulate the production environment for educational and experimental applications [47]. These production environments facilitate the opportunity for students to experience the manufacturing industry with the goal of understanding and integrating knowledge into contextual circumstances. Popular topics for the LF exercises include energy efficient optimisation and lean management of production processes and methods [48]. LFs around the world replicate the dominant type of SMEs in their surrounding area. One example is the Stellenbosch Learning Factory (SLF) at the Industrial Engineering department at Stellenbosch University. The SLF was regarded as still in the process of being developed, but could already facilitate production line setup and streamlining exercises of the value stream simulating manufacturing SME. Other LF examples are the ESB Logistics Learning Factory (ESBLLF) at Reutlingen University [49] and the LPS Learning Factory of Ruhr-University Bochum that is situated in the product development and production industry environment [50], [51].

2.4.2 *Smart Factory*

In 1999, German manufacturing representatives, industry experts and academia started to develop a vision for an intelligent factory of the future. They wanted to create the first of a kind factory that could operate all by itself. They wanted to push the envelope and see how fast they can speed up planning and setup, adapt to rapid product changes during operation, and to reduce the planning effort. In June 2005, the smart factory (SF) in Kaiserslautern, Germany was established [22]. This demonstrator facility was to be the very first research facility for smart production technologies in the world, according to Zuehlke (2005) [22]. Their goals were to develop, apply and distribute innovative, industrial plant technologies and then create the foundation for their widespread use in research and practice. The focus of their research was to design and implement innovative information and communication technologies (ICT) in automated production systems. Kaiserslautern University of Technology developed a hybrid production facility for the production of coloured liquid soap and used this setup to study the shortest setup and changeover times of production between small batch sizes. After the facility was well established, it became a key facility for research and design projects according to [22].

A SF will be the physical building or shop floor where products are being produced, but for it to function properly a digital counterpart needs to be introduced. This digital counterpart will function as a communication and decision-making foundation that will interact between the physical and the digital realms of the SF [2], [52]. Figure 2-4 demonstrates the role of Cyber-Physical Systems (CPS) [1], [2]. They function as a communication network where all the elements of the factory are in communication with each other with the understanding of the capabilities, goals and objectives of each. A SF is, therefore, a non-deterministic and open network in which self-organised objects and services can communicate independently to each other, but also have the capacity to source or delegate work [12], [22], [40], [52].

2.4.3 *Cyber-Physical Systems*

CPS is defined as the integration of computation, networking, and physical processes [53]. The CPS technology builds on the older (but still quite young) discipline of the IoT. CPS integrates the dynamics of the physical processes with those of the software, programming and networking, thus, providing the possibility of modelling, design, and analysis techniques for the integrated whole and, thereby, changing how we use data and information to our advantage [9], [53], [54].

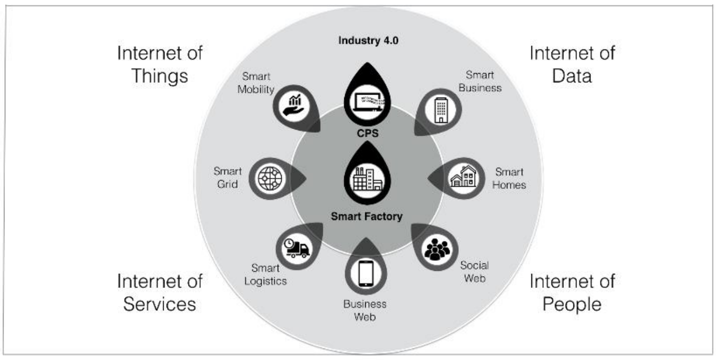


Figure 2-4: CPS and Smart Factory's function within Industry 4.0 and the internet compiled from Deloitte (2015) [1]

Though CPS is a solution to many communication and industrial processing and decision-making problems, it is not a developed concept yet. The following challenges first need to be addressed before CPS can become common in the manufacturing industry [55]:

1. Context-adaptive and autonomous systems;
2. Cooperative production systems;
3. Identification and prediction of dynamical systems;
4. Robust scheduling;
5. Fusion of real and virtual systems;
6. Human-machine (including human-robot) interaction;

The results of CPS and ICT have contributed to the future developments of software and systems that will be able to solve production-related problems. The complexity of production gives new opportunities and challenges for the system and, therefore, research and development into a Cyber-Physical Production System (CPPS) is underway [9]. This signals the inevitability of a merger between the virtual and physical world to produce better simulations as a future trend to replicate the production process.

2.4.4 *Cyber-Physical Production Systems*

A CPPS is the union computer science, information and communication technologies and manufacturing science and technologies [55]. CPPS is the unification of CPS and production systems and is prominently promoted in the Industry 4.0 principles as the future of production systems [1], [2], [12], [40]. The theoretical system elements that can be closely resemble all the functionalities of CPPS are the following [55]:

1. Intelligent manufacturing systems which are expected to solve, within certain limits, unprecedented, unforeseen problems on the basis even of incomplete and imprecise information. Here, artificial intelligence and machine learning methods play a significant role.
2. Biological manufacturing systems, which are based on biologically inspired ideas such as self-growth, self- organisation, adaptation and evolution,
3. Holonic manufacturing systems (HMS), agent-based manufacturing, where autonomy and cooperation are the main characteristics of the entities.

CPPS could be considered an important step in the future development of manufacturing systems. Whether this step would be regarded as the fourth industrial revolution will be decided by the coming generations. Nevertheless, for now, CPPS could be looked at for inspiration with regard to future developments in the field of operation and control within the manufacturing industry.

2.4.5 *Smart Production Systems*

In the field of manufacturing, a recent increase in levels of computerization growing within the industry to meet production requirements has been noted. Smart production systems are similar to intelligent manufacturing systems as described by Monostori (2014) [55]. Such systems are characterized by their incorporation of intelligence into production processes to facilitate more control and include the ability to integrate customers and business partners into the value creation process of manufacturing [46]. Traditional production lines consist of a single line, which manufactures a single type of product or an input-output layout and the machines run along it. In most cases, there is no communication between the different machines in the production line [46]. Through intelligent management of the whole manufacturing process, smart production systems can reduce waste, energy consumption and overproduction.

The objective of a smart production system is to process multiple types of products simultaneously using communication and artificial intelligence principles to plan production value streams [46]. The new production line supports rapid changeover and automatic setup for product variants by sourcing all the necessary information for processing and planning purposes. Data collected from heterogeneous sources are being collectively processed to aid in the production process [2], [4], [9], [12], [40], [56], [57]. Information systems handling data from products and people can be between shared machines, people and businesses [46], [56]. The framework for smart production systems consists of the following elements: CPPS, SF and artificial intelligence (AI). These three elements serves as pillars for smart production systems and can be seen in Figure 2-5.

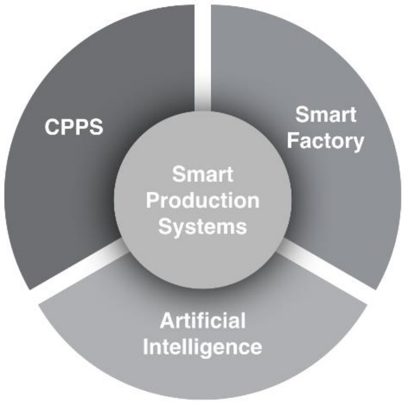


Figure 2-5: Proposed Smart Production System Framework

Smart production systems join into the Industry 4.0 vision. CPPS is the union of computer science, information and communication technologies and manufacturing science and technologies [55]. Smart production systems are a CPPS with added intelligence functioning inside a SF environment. Therefore, for the purpose of this research the definition of smart production systems will be the following: Smart production systems collect big data in a SF via CPPS and intelligently filter information to convert knowledge into commercial value. Note that this definition includes big data, which is a concept that entails information mining from multiple commercial data sources [4], [13], but for the purpose of this research only data within the manufacturing industry scope will be incorporated for concept demonstration. Nevertheless, there are challenges that have to be taken into account before smart production systems can be incorporated successfully [9], [46], [55].

2.5 Current Production Related Information Technology Architecture

2.5.1 *Data and Information*

Data are often required in order to identify and understand a problem. Specifically, data can be used to validate assumptions, estimate model parameters as well as validate models and are usually collected at every step in the process. Data represent characteristics of people, objects or events [57], [58]. Data is not information, rather information describes or explains data [57]–[59]. It is therefore important to determine what data are necessary to solve the problem and then determine the process of gathering the data, and collection sources could vary from internal to external [58]. These sources, in turn, vary from historic data to real time data that can further be broken down into machine or human resource data [58]. Information serves the function of conveying data in a representable, collective and understandable way in context [57].

2.5.2 *Internet of Things*

According to Stankovic (2014), IoT can be defined as an intelligent network of connected things that communicate with each over the internet [30]. The purpose of the IoT and the reason for the recent growth and interest in this field results from the revolutionary information exchange between these sensing devices and is classified as the first means of connecting the physical with the cyber world [30], [56], [60], [61]. Now, thousands of heterogeneous devices can gather information and present them to one another. Currently, this technology is used in home automation and weather monitoring, but in the near future, the technology would most likely see implementations in the form of smart cities, smart transportation and digital health amongst others [30], [62]. IoT and related technologies would combine the sensing devices; their operating conditions and descriptive operation environment information. Future developments, according to Chen et al (2014), include improved data gathering techniques and intelligent processing [60]. He also suggests that before its general recognition, certain challenges must be addressed if IoT is to be fully harnessed. These challenges include the standardization of the architecture, communication, privacy and security as well as the related business model of IoT [60], [61].

According to literature, the next phase of IoT would consist of creating business models around the accessibility of information [30], [56], [63]. With the physical and the cyber world now more closely integrated, the opportunities for smart services using smart products will be possible in the near future [21], [56]. New possibilities of self-organizing systems, smart production systems and energy management systems would form from the collection of information and the intercommunications of devices [21], [60], [62]. There are emerging opportunities for IoT and related technologies. For example, near-field communication (NFC) and radio-frequency identification (RFID) could be used to tag and track the movement of products right through the value stream. Augmented reality applications on mobile devices could be incorporated to train technicians using various instruments and tools or help them through maintenance issues and innovations in mobile adaptation [64].

2.5.3 *Automation Pyramid*

Figure 2-6 provides a breakdown of the automation pyramid with its levels of management separated by data sourcing and processing sections to provide sourced information from the lower levels to the level above it. These three managerial levels are device (or shop floor), Manufacturing Execution System (MES) and Enterprise Resource Planning (ERP) level and each has their own responsibilities within the organisation and produce organisational data that flows in an upwards direction towards the next managerial level [22]. The automation pyramid and an example of how sourced data flows upwards from a raw data level to valuable operational information is displayed in Figure 2-6 [21], [22], [65].

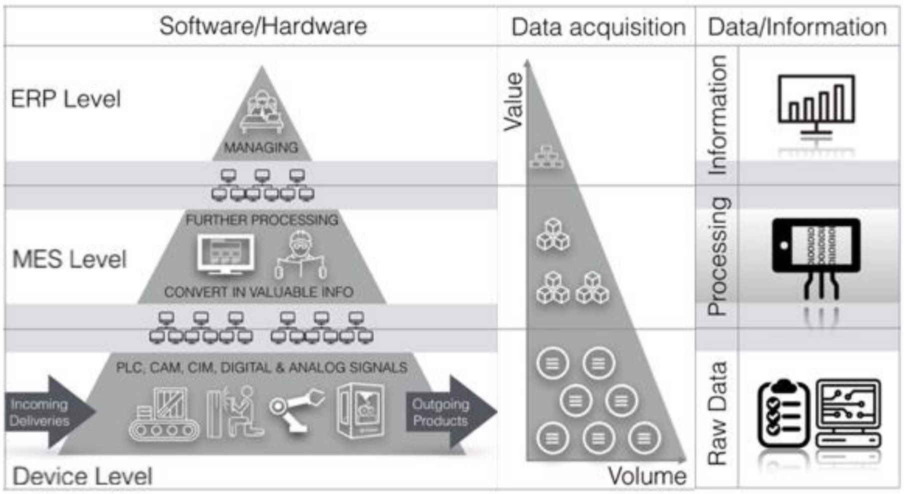


Figure 2-6: Automation Pyramid compiled from Zuehlke (2010) [22]

The device floor can source PLC, computer aided manufacturing (CAM), computer integrated manufacturing (CIM), and digital and analog signal from operated machinery together with human operator information to the next level. The MES level, when presented with this data, can then produce information regarding scheduling and process control management, and/or equipment, material personal and quality management through data acquisition and performance analysis. The ERP level functions on an organisational level and can use the data of the MES level together with market predictions to handle market and sales, customer service, future expansions, human resources and the finances of the enterprise [66], [67]. For purposes of this research, two control opportunities are discussed on the MES level of the automation pyramid architecture that promotes improved decision-making and resource management [7], [22], [65], [66]:

1. Inventory Control: Inventory and stock can be tracked using IoT and related technology to monitor the warehouse capacity, layout of inventory inside the warehouse, the amount of inventory and the receiving and delivery dates.
2. Distribution of Resources: Managers on MES levels could track their entire workforce from their offices, see where major activity is happening and plan when some of the resources need to be freed up for peak times. Allowing managers increased control over the entire workforce.

The automation pyramid architecture was developed to comply with IoT and related technology to distinguish between operation levels and to show how the levels of management can interact with each other through information exchange. This architecture will pave the way forward and introduce higher levels of information sourcing when industrial automation like machine-to-machine (M2M) communication, machine-learning and IoT within manufacturing industry are being introduced and implemented [21], [22], [68]. With respect to the scope and goal of this study, resource efficiency and user specific information produced per level will be used as application opportunity.

2.5.4 *High Resolution Production Management*

Organisational information is becoming more accessible due to smart technologies being implemented in the organisation as part of the IoT implementation technology, which in turn, promotes future implementation of production IT architecture within manufacturing [56], [69]. The basis of high resolution management (HRPM) systems can provide full transparency into the entire organisational processes, multi-level operational planning and scheduling while enabling real-time decisions to be made [9], [55], [69]. HRPM is becoming the new solution to scheduling problems in lean manufacturing [69], [70]. This system incorporates synchronization within production processing to help with scheduling and control issues within the value stream. In real time, the system incorporates the production time length, the material provision times and the adaptation to assembly operations with the aim of fully utilising the entirety of the facility resources in order to eliminate process inefficiency [56], [69]–[71].

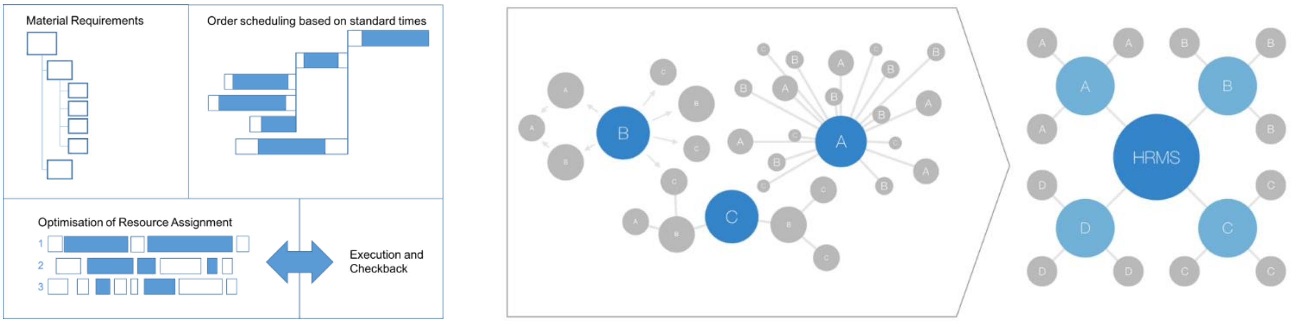
To succeed in creating a HRPM system, a multi-level, hierarchical decision-making process must be designed that accommodates the entirety of possible input and outputs of a production value stream. This designed decision-making processing system needs be strategic, tactical and intelligent in nature. However, due to the mere size of the internal and external factors that act on such a system, an alternative that can handle all the inputs and determine outcomes by itself needs investigating. According to Schuh (2007) [69], HRPM describes the approach of managing production processes in real time. In a paper on this subject, Schuh investigated three challenges within planning and control and came up with three solutions addressed by HRPM system. The three challenges are as follows:

1. Real-time ability: A real-time system is one that can respond to data signals that convey trigger events fast enough to satisfy a specific requirement. Real-time in production includes continuous data sourcing and updates from the entirety of the production environment in order to provide future planning information to the MES.
2. Planning Consistency: Here, the problem of using effective planning and control techniques within lean manufacturing principles are suggested. Optimising within the production parameters as a challenge in planning when anticipating restrictions is introduced.
3. IT architecture for production systems is suggested as the core problem of current models.

In response to these challenges, Schuh (2007) suggests three elements of the HRPM systems that can overcome them [69], namely:

1. Sensor Actor Network: A low-level communication platform is suggested to create quick feedback-control information of operations. These can be incorporated on machinery or with the workforce with mobile technology solutions.
2. High Resolution Order Management: An optimisation simulation can order the allocation of resources in the production process. This element provides the necessary degrees of freedom within control and planning that permit new assignment, projections and deviations in production process.
3. Service Orientated Structure: This element of HRPMS covers the functionality of material and resource requirement planning and the administration of this data. It also addresses the problem of heterogeneous design of the IT architecture with simplification of design.

High Resolution Order Management is introduced to simplify the amount of information that needs to be addressed when an optimisation of resources assignment is executed. The material requirements and order scheduling based on standard times are only two of the necessary information sets that are incorporated for this element to properly function [69]. In Figure 2-7, the planning logic of just these two information sets is presented.



(a) *(b)*

Figure 2-7: HRPM demonstrating (a) High Resolution Planning Logic and (b) Service Orientated Structure compiled from Schuh (2007) [69]

The planning logic represents the material requirement list and the time schedule information a project can have to determine the optimised resource allocation on three production lines. Afterwards, the execution and check back function correlates the optimised resource planning to the actual activities with the aim of improving future planning.

The second is the Service Orientated Structure. The simplification of this model to deal with the heterogeneous input sources results from the structure it creates for data convergence. The model makes use of clusters where information is gathered and is based on the Sensor Actor Network solution provided by Schuh (2007) [69]. In the left block of Figure 2-7 (b), the three production lines are separately addressed with all the information captured available in a messy state. On the right side of the figure, the same data is captured by a single cluster and, therefore, can easily be managed and presented to the HRPM system or other PRITAs.

2.5.5 *Artificial Intelligence*

AI is intelligence exhibited by computers or machines. By definition, an ideal AI would be a flexible and rational agent, which could interact with its environment in a way that allows it to achieve a goal [72]. These goals are mostly deductions, reasoning and problem solving of some sort that could be given to the computer and using an approach like machine learning to solve it [72], [73]. This is when the computer or machine solves a given problem by being repetitively introduced to the problem and variations thereof [74].

Deep Learning (DL) is a machine-learning model that can be explained by recent developments in the field of AI. Google has recently achieved great success with its DeepMind project [75]. DeepMind is an unsupervised learning method that is applied to two areas: The first was image recognition by teaching itself the differences of objects within images. This same concept was also introduced into simulations (or numerically) with the use of old school 8-bit games [76]. An example is where DeepMind playing Space Invader repeatedly and improving at the game until it could predict where the aliens will be and, therefore, shoot a bullet towards its future location [76]. The most famous example is definitely the Go application of DeepMind [77]. This game has an infinite amount of outcomes and, therefore, cannot involve calculating future outcomes, like in the instance of chess. DeepMind actually had to learn how to win the game, by watching people play the game, playing against itself and then playing and winning the best human player in the world [75]–[77].

2.5.6 *Fuzzy Logic*

Developed by Zadeh in 1965 [78], [79], fuzzy logic is a form of many-valued logic where the variables may be any value between 0 and 1 and is, therefore, considered to be “fuzzy” [80]. Fuzzy logic has been applied to many fields, from control theory to artificial intelligence [81]. It is based on a system of non-digital, continuous & fuzzy without crisp, boundaries algorithm that need to adhere to a set of rules. Its main advantages are its ability to deal with vague systems and its use of linguistic variables.

Linguistic variables are words that we use daily to indicate conditions of things. For instance, we can say that the water temperature is cold, warmer, warm, hot or very hot. In general, the values of a linguistic variable are generated from a primary term, for instance: excellent and poor is in this case linguistic variables of quality [81]. That makes cold, warm and hot linguistic variables of temperature. Fuzzy logic relates the linguistic variables into a mathematic algorithm of IF-THEN cases that can show indication of how warm the water is on a cold to hot scale. An example is: IF 70% hot water is added to 30% cold water THEN it would be 60% warm. A complicated graph goes with this explanation, but a case study dedicated one will be explained in a later section of this research report (see section 3.4.3). Fuzzy logic can create an accurate quantitative model that can determine appropriate actions or change in conditions. This leads to faster and simpler program development of system controllers and can also function as a decision support system tool for managers [82].

2.5.7 *Mobile Technology*

A literary case study done by Forbes distinguished aspects that support the importance of mobile technology within all industries. Forbes outlines the following: 81% of ERP executives see mobile technologies to be important strategically [25],[83],[84]. And 86% of CEOs agree that future success will be dedicated to understanding and incorporating digital mobility [85]. Mobile technology does not limit itself to simply shifting work from desktop computers to mobile devices, but will enable opportunities such as thorough management applications, device integration and process synchronization. Mobile technology models within lean manufacturing represent the strive to mobility and how users' location does not influence the information receiving and collaboration capabilities [25]. Mobile technology should embrace this new movement for the following six reasons [86], [87]:

1. Portability: mobile applications can be used for on-the-go quality checks, alerts for problems or breakdowns and instant updates on project statuses.
2. Real-Time Problems and Real-Time Solutions: instantaneous awareness of true situational conditions can decrease reaction time and enable learning from the factors that leads up to malfunctions or problems.
3. Health and Safety: wearable technology is capable of monitoring the conditions of the workers for stressful working conditions, for instance, too hot or too cold, and take immediate effect/action.
4. Precision Monitoring: Improved indication of your stock levels or locations of your logistical department vehicles or availability of staff can influence the effective coordination of a company.
5. Relatability: Simplifying the logging of data through mobile technology would make workers more effective at capturing information when it is not a tedious activity.
6. Affordability: Lately, the affordability of tablets and mobile devices are changing the perspective of the usefulness of such devices.

Mobile technology has the potential to play a role in almost every step in the manufacturing value stream, right from raw material procurement to supply chain to delivery. From quality check reports to quote approval, we can see multiple processes where mobile technology can provide lean alternatives. In other words, mobile technology does not limit itself to simply shifting work from desktop computers to your mobile phone, but provides a great deal of other opportunities. Opportunities such as management applications, device integration and process synchronization are all achievable. The benefits of mobile technology and how it can revolutionize manufacturing are outlined here, according to Columbus (2015) [85]:

1. Integrating mobile customer-relations managing systems with distributed order management, pricing and fulfilment to improve customer responsiveness;

2. Generating quotes for build-to-order products that reflect the latest pricing and delivery dates available;
3. Making distributed order management more transparent to sales while increasing order fulfilment accuracy;
4. Improving supplier traceability and quality levels using real-time analysis and reporting;
5. Replacing manually-intensive inventory management systems with enterprise-wide mobile inventory tracking, traceability and reporting systems,
6. Monitoring production workflow performance using dashboards accessible from mobile devices;
7. Tracking machine-level compliance and providing alerts to production engineering when maintenance is required;
8. Reducing Field Service call cancellations and delays by accurately communicating parts and staffing requirements;
9. Improving logistics and supply chain coordination with suppliers using mobile technologies; and
10. Making manufacturing intelligence the new normal in production operations.

These are all elements that could be implemented within a company and its productions operations with the added use of mobile technology and smart phones to input or access the information [85]. Mobile technology and lean manufacturing can enable users and their location do not influence the information receiving and collaboration capabilities [25]. Thus, when considering all the systems and their corresponding functions within the manufacturing value stream, the possibilities for mobile technologies implementation are endless. At every breakdown and/or connection between in the value stream within an organisation, a mobile technology platform can be developed to:

1. Check,
2. Source data,
3. Have user input,
4. View important KPIs,
5. Make production line alterations,
6. Communicate to the workforce and
7. Help with maintenance.

Lastly, in a study conducted by Motorola, there was a clear indication that the stress levels of workers declined. The reduction of workers' stress, improved relationships and boosted productivity are some of the biggest benefits an organisation can gain when making the switch to mobile technologies according to the study [86]. This is just the beginning, there are many more positive implications of the technology incorporation within the business, production and manufacturing scope to boost productivity and create commercial value.

2.5.8 *Cloud Computing*

Cloud computing has the ability to harness new processing capabilities that include all the necessary ones for complex data collection, handling and processing. They are already capable of processing big data, have IoT sensors and detectors communication, reconfigurable and robust applications that provides rich and quick access for mobile and computer clients [88]. The goal of cloud computing is to solve data intensive problems with reduced power consumption [88].

Cloud computing is a metaphor for its operation describing both the connection type and the workings of it. The cloud metaphor shows that it is not connected with physical wires and the computing aspect serves to show the processing of functionalities that sometimes overlap and, therefore, do not have clear boundaries[89]–[91]. It is an internet based service that provides shared computer processing power to each other and can share resources to other computers and/or devices on demand [92]–[94]. This service is becoming popular due to no physical computer infrastructure such as servers, networks or storage and therefore requires a low initial investment and low maintenance [90].

2.6 Visual Management Systems

Visual management system is a set of techniques for creating a workplace that embraces visual communication and control in the work environment. Visual management is a tool that attempts to improve organisational performance through connecting and aligning organisational vision, core values, goals and culture with other management systems such as work processes and workplace elements by means of visual stimuli [66]. These stimuli communicate quality information which helps people make sense of the organisational processes and progress, in context and at a glance [29], [95], [96]. The information will have the following characteristics: necessary, relevant, correct, immediate, easy to-understand and stimulating. It is a management approach that utilises either one or more of information giving, signalling, limiting or securing visual devices to communicate information more quickly and easily. In so doing, the whole working environment becomes increasingly self-explanatory, self-ordering, self-regulating and self-improving for the individuals that is trying to make sense of it [18].

Visual management has a very rich and creative historical background, dating as far back as the 2500 BC when the Egyptians used it to aid in their construction projects of the pyramids [19]. It utilizes a range of functions in an organisation and tracks operations and processes over multiple managerial levels [19], [66], [95]. According to Tezel et al (2005) [18], [19], visual management tools can provide nine different functions among them: transparency, discipline, continuous improvement, helping with job facilitations and on-the-job training, creates shared ownership and teamwork opportunities, management by facts, simplification and unification. According to Tezel et al (2005), visual management systems are deployed for the following reasons [19]: To see the problem, to communicate recommendations, to easily solve problems, to communicate the problem solving solution, and to communicate results to others involved. This process is captured in Figure 2-8. An organisation that wishes to implement visual management tools would start by identifying the specific needs of said organisation and then implement various visual tools to achieve improvements and/or solutions according to the identified needs.

Figure 2-8: Reasons for deploying VMS according to Tezel et al (2005) [19]

Kaoru Ishikawa, the inventor of the Fishbone diagram, supported the idea that 95% of all quality related problems could be resolved with the use of basic visual tools [19], [97], [98]. Currently, most of the implemented visual management tools have been based on manual systems. Lego blocks, coloured string or ribbons on white boards have been used and implemented successfully in big and small organisations. Currently, there is a great number of established manual VMS that have been developed, deployed and depended on. However, due to the advances in information technology, the implementation capabilities thereof have also evolved [19]. The new digital age can make real-time improvements in measurements, make data collecting possible from multiple sources to produce holonic information of an organisation. Communication and interpretation of the information ca,n therefore, lead to improved behaviour analysis of an organisation and provide quick response to change [19], [29], [95].

Digital VMSs are currently being implemented in a variety of fields. VMSs provide new functionalities that include real time updates, being clear and concise, flexible and customizable. What follows is a brief discussion of a few visual management tools and systems that describes the possibilities of current technology and implementation possibilities:

2.6.1 *Visual tool*

Angelini et al (2014) produced a paper entitled VIRTUE: A visual tool for information retrieval performance evaluation and failure analysis [29]. Within it, they describe an Information Retrieval (IR) system that consisting of search engines that could access data in digital libraries and visually assess them. VIRTUE is an abbreviation for Visual Information Retrieval Tool for Upfront Evaluation and is an innovative visual analytics environment. This tool is the first of its kind to integrate and support the ease of performance and failure analysis. The environment has been designed using a user-centred design methodology exploring different visualizations and interaction mechanisms. VIRTUE supports performance analysis on a topic-by-topic basis and opens the opportunity to statistically analyse relevancy between topics. The target users of VIRTUE are researchers and developers in the IR who need to understand and improve their systems. It may also find application in the production contexts as a tool for monitoring and interpreting the performances of a running system so as to ensure that the desired service levels are met [29].

2.6.2 *Visualisation Methodology*

A paper by Hu et al (2012) entitled: Development of a Method for Visualization and Evaluation of Production Logistics in a Multi-Variant Production is considered as case study for visual management implementation methodology [99]. Due to the growing variety and complexity of products, the current traditional logistic aspect of sourcing and distribution is struggling to keep up. This is blamed on the declining transparency of the value chain within the manufacturing industry. For this reason, a methodology that enables a transparent, clear, holistic visualization of the value stream that includes the entirety of processes and product flow was developed. Visual tools indicate their control system, their inventory locations and their physical logistics processes from the supplier to the final assembly. In a practical application, the developed logistical value stream is convenient for a fast and simple visualization of the production supply. Through the intuitive and transparent representation of the problems along the process, it is possible to generate alternative processes. With the logistic value stream, it is feasible to control the complexity of logistical systems in a versatile production [99].

2.6.3 *KPI Dashboard*

A paper entitled Corporate dashboards for integrated business and engineering decisions in oil refineries: An agent-based approach [10] by Bauer et al (2014) is used as case study for KPI dashboards. In this case study, the focus on identifying KPIs that can help represent the interactions among the market forces, the management policies, and business and engineering decisions are introduced. Designing the measurement schemes across various businesses and engineering departments were tested in a simulated environment that evaluated which could produce the most informative KPI dashboard. A dashboard is a digital human–computer interface that connects the decision-maker to the integrated business and engineering simulation and optimization model. A dashboard could also be defined as a device that facilitates presentation of information. These dashboards and KPI combinations are tested under different product market scenarios and the sensitivity of changes/actions evaluated. It should be noted that a variety of other learning algorithms are also applicable when modelling the decision-making models. However, the simulation in this study was primarily aimed at demonstrating how a human decision-maker and an automated decision agent, like the dashboard, can interact and collectively improve an organisation’s performance [10].

2.6.4 *Prototypical Example within the Manufacturing Industry*

HaldanMES is a visual management tool which collects equipment data from the shop floor in order to generate a report that can be displayed on a dashboard [100]. Figure 2-9 below is an example of the HaldanMES visual report generation software and shows an OEE and losses dashboard. OEE is a function of machine availability, performance and product quality of the output. These three factors is determined in percentages and then multiplied with each other to produce the OEE percentage. The tool was initially tested in an automotive part manufacturer called Hansen’s Engineering to display CNC operation information [101].

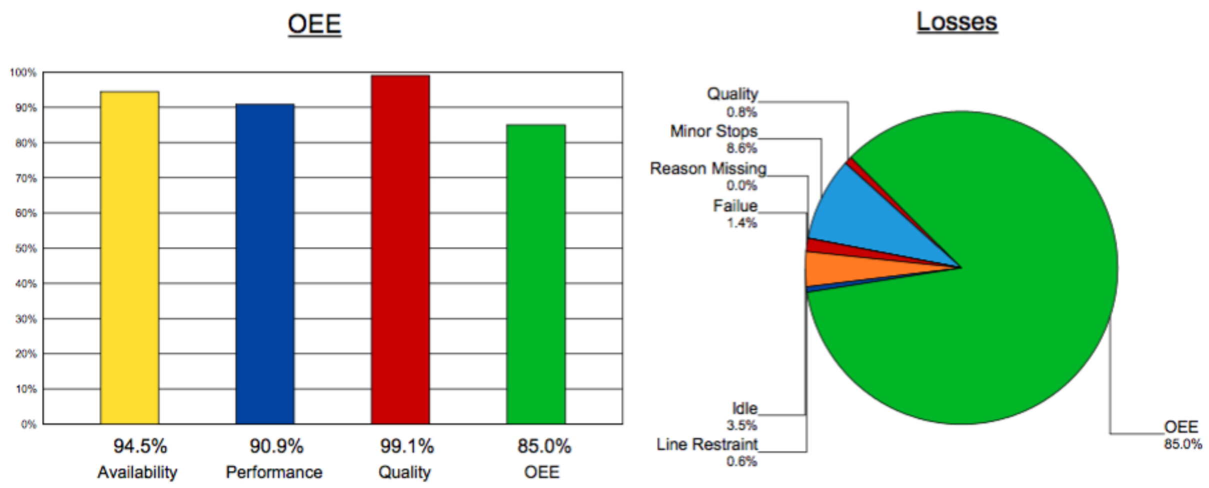


Figure 2-9: HaldanMES OEE dashboard from HaldanMES (2016) [100]

During a case study to determine the influence of an OEE report generation software on the company, several operational changes were observed [100]. For example, less meetings are needed between the management levels in order to effectively communicate company performance and problems within the company. Shop floor staff are motivated through the constant display of their machine's real-time OEE statistics (shop floor awareness), and machine operators and shop floor managers could also be held accountable when the OEE is not up to standard. In addition, strategic and informed decisions can be made regarding long-term investments when upgrading machinery by analysing long term OEE reports [100].

2.7 Conclusion

This chapter sought to introduce the reader to the concepts discussed in order to form a basis of knowledge on which this research can build. The literature layout indicates the succession of the research scope. What is missing in existing approaches and what needs to be solved by this research? Indeed, it is the case that VMS and PRITAs are discussed in theory and implementation thereof investigated, but no development, prototyping or testing has been done in the manufacturing industry field of data sourcing and processing with the goal of information conveying. Further research and design of these systems need investigating and a case study for research purposes implemented to overcome the numerous problems in the initial stages of these new systems.

In line with the thesis outline provided in chapter one, the next chapter discusses the research methodology employed in the execution of this study.

Chapter 3. METHODOLOGY

3.1 OVERVIEW

The systematic approach of this chapter details the two exploratory process sections detailing the development phase of the PRITA and VMS model, followed by a case study section that investigates the model. Through defining and discussing VMS's capabilities and then addressing the implementation areas in which it can flourish, VMS's importance in the manufacturing industry became apparent. Thereafter, investigation into implementation and integration of VMS within industry starting at technology implementation investigation and PRITA system development in the manufacturing environment with case studies is investigated.

3.2 VISUAL MANAGEMENT SYSTEM

3.2.1 *Overview*

This section details the process of defining, designing and detailing the implementation methodology of a VMS. The goal is to investigate the methods of data sourcing and processing to produce valuable information that can be acted upon. This process will consist of an investigation of the entirety of the operations and functions of the VMS needs in order to produce a model with vital functionality elements.

3.2.2 *Model*

This section discusses the process embarked on to produce the VMS model and element details. The first step is revisiting the research design method and use it as basis of model investigation. Figure 3-1 is a demonstration of the objectives of a VMS. Its function is to convey information about production operations and in so doing, creates an information feedback loop of operations' statuses to determine where operational improvements can be made. These operational improvements can be in the form of resource management and/or planning and scheduling solutions. Therefore, it is a hand-in-hand relationship of providing information and acting upon it that forms the basis of the VMS model.

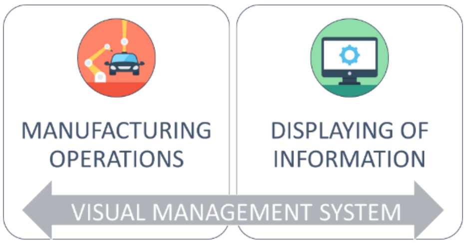


Figure 3-1: Exploring Visual Management System

This relationship is investigated to determine the opportunities VMS has within the manufacturing industry of current and near future factories. When exploring VMS within this capacity, it is necessary to investigate the underlying information technology (IT) elements that need to be integrated before proper data sourcing, processing and communication in a secure fashion can commence. This architecture can be seen as a third set in the hand-in-hand relationship that sits between the manufacturing operations and information displaying pair. This relationship is illustrated in Figure 3-2.

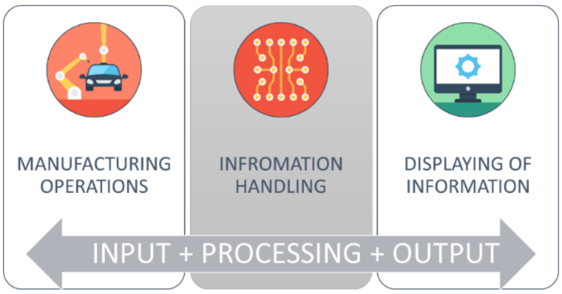


Figure 3-2: Exploring the Information Technology of Visual Management System

The new information handling component of VMS makes the sourcing of data from the manufacturing operations and providing it to VMS as information, a possibility. This input information can consist of both equipment and human data. The output of the VMS comprises information displaying techniques such as KPI dashboards in the shop floor or higher management levels, which provides operational performance information in updated reports on desktop or mobile devices.

The first and most important element of the VMS model is the visualization of information by the use of visual tools to convey comprehensible information quickly and effortlessly. An important factor to consider here is that it is necessary for operators to view information in an orderly and presentable fashion. Thus, the first model element will be visualization tools that can relay operation information effectively with the use of graphical performance indicators. These can be timelines, bar and line charts, dials and gages, or similar statistical or graphical methods that can provide accurate and instant relaying of information. Additional text could be incorporated to provide detailed description of the processes or people involved within the projects.

Accompanying the first element, is a database where the data is stored with the purpose to produce the digital output information for the graphical performance indicators. From this database, information is extracted to produce the visualization tool. This provides the opportunity for multiple input sources' data sets being in the same place and updated as the data is being made available. This leads to the second element, smart production system as a VMS element. Such an element can cluster data together and produce information regarding other overall operational KPIs thereby providing the opportunity for smart data analytics and trend spotting. It is the case, therefore, that smart information handling and processing techniques are introduced here to perform interpretation of holonic operational data. The VMS element has the prospect of creating an interactive information relaying environment in which the operations of the entire value stream can be evaluated to create action items for improved operational efficiency and effective resource management.

The third element has a limiting effect on the access of information. Seeing that all the data and information is available to be displayed using visualisation tools, there must be levels of access to the data on a secure and instantaneous platform. The third element, therefore, creates the opportunity for information to be displayed only to those who has access to it. A user-specific access element can provide the VMS the ability to limit access of all users to only the data that is specifically meant for them, thus, creating a hierarchy of operational performance indicators with security restrictions. This element also has the ability to document the access to information and the actions taken to improve production operations.

The last element is one that can truly improve on the responsiveness of operational procedures and information relaying. Smartphones and tablets have become an everyday commodity in our daily life. By incorporating them into the VMS model as an element is the next step of streamlining operational decision-making. Incorporating hand held devices, multiple possibilities of using them as input, output or processing devices becomes opportunities to be investigated. Such devices are quick and responsive, can handle multiple operational input types and deliver on informative information thereby displaying capabilities even on their limited screen size and still provides the VMS model the ability to be agile while focused on efficiency.

The longitudinal research design together with an iterative investigation process produced the VMS model with its elements and can be seen in Figure 3-3 below.

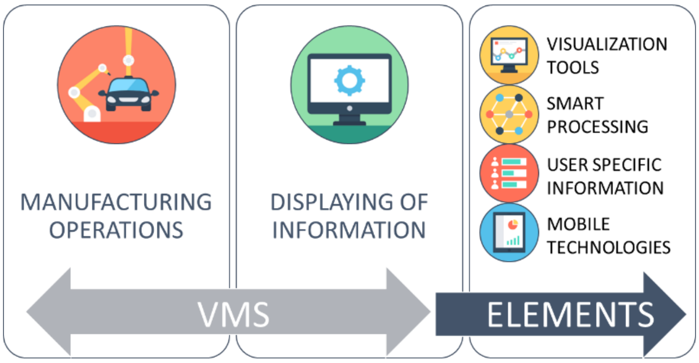


Figure 3-3: VMS Model and Elements

Considering the above and for the purpose of this document, the author derived the definition of VMS as the following: VMS is a holonic data sourcing, processing and information displaying system with the goal of heuristic process understanding. This definition describes the method that VMS will source and process information from multiple sources, whilst still being able to focus on important single source information, and through analyse of the processes and methods of interpretation, provide valuable information regarding the organisation's operations.

An example of this process would be to install a data capturing device on a CNC machine on the shop floor that gathers power consumption and idle time data and considering these two data sets with their corresponding timestamps as input data. These two sets need processing and can be combined with other data to provide overall operational information. For instance, using the power consumption data together with tooling properties of the CNC machine, an output device can display manufacturing effectiveness of the operation of the CNC cell with KPIs. Another output example would be incorporating the idle time data set with a schedule to produce a productivity KPI. This, in turn, provides output information on current manufacturing operations that the management could interpret to create action items on these factors if they are below standard or underperforming.

3.2.3 *Example*

Figure 3-4 shows a VMS dashboard example and features a combination of output displays using a variety of visualization tools. It collectively represents a dashboard and is an example of an implementable VMS within the shop floor of a factory. The dashboard also provides information to the shop floor workers, which in turn, can influence their or their operation's performance. By providing information regarding their current operation while the projects are still underway, the goal is for them to evaluate their own performance and be able to improve on the effective use of its equipment or operations. This dashboard provides an output concept of what can be achieved as well as the layout and cell function as discussed after Figure 3-4.

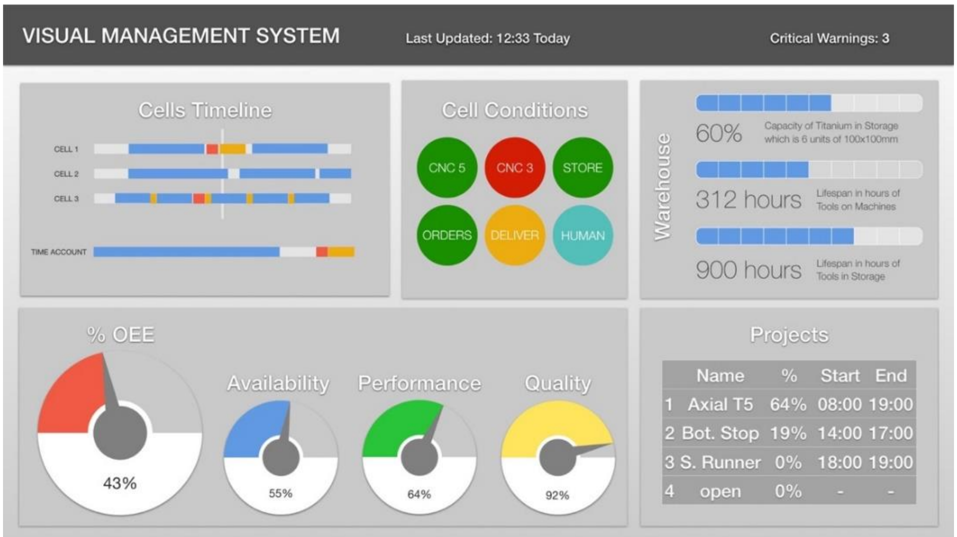


Figure 3-4: Prototypical Dashboard Example

In this dashboard illustration example, there are five different information cells of a typical shop floor being addressed. Starting top left and clockwise:

1. The cell timeline is included indicating the cell activity and its corresponding job or project lengths with additional information for breakdown, changeover and standstill information,
2. The cell condition light up buttons to flag operation and critical warnings of cells,
3. The warehouse capacity and storage item levels are displayed in bar charts and percentages,
4. Project titles with the progress, the beginning and estimated time of completion thereof can be displayed using a table format, and
5. OEE expresses the availability, performance and quality of the activities and products produced.

Here, the two text fields in the top bar should be noted. The middle one indicates the last time the VMS was updated and the other indicates the amount of critical conditions or warnings within the factory floor. These two text fields have the viewers' immediate attention. This example of a shop floor dashboard can be installed in the shop floor environment and can be used as a static report feedback tool (a tool or dashboard that has no interactive capabilities) or a dynamic one with touchscreen capabilities and providing more in-depth information to the user. The more information is made available to the user, the more opportunities for identifying improvement is presented. This example is to encourage considerations of operational information that is vital for display on a dashboard or similar VMS output.

3.2.4 *System Operational Requirements*

In general, VMSs is designed specific to the required outcome that is expected from the system interfaces and the objectives of the customer or user. In this section, the system is broken down to become a methodology of design, requirements and operations of such a system. This enables the system to be designed in steps with the goals set by the client or users in mind. The process of identifying and translating a problem or shortage into a definition of need for a system that can provide a solution will be discussed later in this section.

A complete description of the need, expressed in qualitatively related criteria whenever possible, is essential. It is important that the problem definition reflects true customer requirement, particular in an environment of limited resources. The need analysis done by the customer or user should be performed with the objective of translating a broadly defined want or need into a more specific system-level requirement definition. This process could be achieved by posing questions such as the following:

1. Where in the production process is time or resources being wasted or underperforming?
2. How well is the equipment being utilized and what do their future schedules look like?
3. Who is in charge of what production projects?
4. How can data of operations be better utilized?
5. Where is such a system necessary to fulfil its goal?
6. Can the implemented system provide an effortless solution or not?

These questions are important to describe the problem definition and opportunity investigation of a VMS within an organisation. The ultimate goal is to define what is needed first, and then later determine how to solve the problem by breaking the problem down into steps that are addressed to provide a whole solution. The next step is planning and solution generation in response to the need identification through a process of KPI investigation relative to the organisation’s value stream processes. Here, the initial planning activities together with the technical requirement for the VMS are simultaneously determined. While the specific classification for a top-level plan may differ for each system, the objective is to prepare a plan providing the necessary guidance for all the subsequent managerial and technical activities needed to sustain a VMS is essential. These activities differ within industries or organisations, but for purposes of this research, the examples focus on manufacturing activities and/or industry. Having justified the need for a VMS, it is necessary to:

1. Identify various system-level design approaches or alternatives that could be implemented to achieve the same outcome;
2. Evaluate the feasibility approaches to find the most suitable solution in terms of performance, effectiveness, maintainability, user friendly, and future developments; and
3. Recommend a solution through concept selection methods.

The investigation process into developing system operational requirements that can describe the functions of the system to accomplish its intended purpose needs addressing. This will be achieved by incorporation of an operational scenario VMS within the manufacturing industry. The operational requirements defined for a VMS can make use of the following scenario-related considerations:

1. The time necessary to process a project,
2. Project process time and turnaround time,
3. Facility utilization or resource management,
4. The ratio of time utilized to the time available for use,
5. Energy utilization in the performance of completing projects, and
6. Total facility cost for system operation and support.

Qualitative outcomes need to be considered together with the above questions. Here, defining system operational requirements and maintenance models, identify and prioritize KPIs are, therefore, considered important. KPI are quantitative values that can be estimated, predicted, and/or measured to describe a system's performance. These KPI are best determined during the conceptual design phase and are system specific. However, the method of sourcing and processing of organisational data to produce the necessary KPIs and VMS requires information handling solutions and the identification and production related information technology architecture (PRITA) is discussed in the next section as part of the exploration part of the methodology.

3.3 Production-Related Information Technology Architecture

3.3.1 *Overview*

After the completion of the definition process of VMS, the system design then requires elements for IT support architectures. This section discusses the implementation of VMS as a technical system and investigates the process of IoT and related technology implementation with regard to PRITAs. In this section the problem, need identification, system design and operation requirements of PRITAs are discussed. The focus now shifts to discussing the system implementation activities where the system functionalities needs to be determine by a correlation study between VMS elements and PRITAs functions support. This correlation study refers to the actual hardware and software functionalities that will support the VMS elements. Here, the PRITA systems and their possible functions are determined through a strong and weak correlation test, and followed by functionality clustering. Thereafter, the engineering design and technologies section discusses how the selected PRITA systems could support the functionalities of VMS.

3.3.2 *Model*

The PRITAs evaluation process is conducted by assessing its ability to perform tasks or fulfil the VMS elements' function properly. PRITAs should provide VMS the necessary information that would enable the organisation to continue without creating extra work for employees. The functions breakdown of the PRITA systems is heavily dependent of data collection, storage and distribution of information in a secure fashion throughout the organisation. According the specifications of the VMS model, therefore, the functions that the PRITA must adhere to include:

1. Single or multiple data inputs,
2. Data collection platforms, clusters or sectors,
3. Data sorting and processing capabilities,
4. Security and Communication,
5. Data storage
6. Intelligence,
7. KPI generation,
8. Production relevant information, and
9. Visual tools and visual display techniques.

PRITA systems that are able to support the above-mentioned functional requirements are listed below. This list was created after a literature study of similar systems in the research scope that discussed implementation opportunities within the manufacturing industry to support production process data sourcing and processing. They were the following:

1. Automation Pyramid
2. High resolution production system
3. IoT
4. Smart factory
5. CPPS
6. Smart production systems
7. Cloud Computing
8. Mobile Technologies

In Table 3-1 below, correlations between the VMS element functions and PRITAs determined with strong and weak correlative indicators. The indicators are identified by investigating the specific systems' operational features according to literature. A comparative functions analysis is used to assess the operational feature performance of the system and determine the combinations in which they can function together. These correlations are then incorporated to determine the collective PRITA and VMS model.

Table 3-1: PRITA and VMS function correlation analysis

	Function	Single or Multiple data inputs.	Data sourcing and clustering	Data processing	Data storing	Security and Communication	Intelligence	KPI generation	Production Related Information	Visualization
System										
Automation Pyramid		x	x	+	x	x			x	+
HRPM		x	x	+	+					
IoT		x	x	+	+	+				x
Smart Factory		x	x	x		x	x	+	x	+
CPPS		x	x	x	+		x	x	x	
Smart Production Systems			x	x	x	x	x	x	x	+
Cloud Computing			x	x	x	x	x	+		
Mobile Technology		x	x	+	+	+		+	+	x
		Legend: x Strong correlation; + Weak correlation								

From Table 3-1, clusters emerged that showed strong correlations of PRITAs that can perform the necessary functions of VMS elements. Although, there were several combinations of clusters, the four clusters that addressed VMS element compliance can be seen in Table 3-2. These four clusters showed promising grouping of functionalities to perform the necessary sourcing and processing of data required by the VMS elements respectively. It needs mentioning that other cluster combinations are possible due to the table not being a one-to-one correlation list according to importance of functions, but rather a list of functions and a system correlation study according to function and PRITA compliance.

Table 3-2: Clustering of PRITA and VMS function correlation analysis

System / Function	Single or Multiple data inputs.	Data sourcing and clustering	Data processing	Data storing	Security and Communication	Intelligence	KPI generation	Production Related Information	Visualization
Automation Pyramid	x	x	3. +	x	x			x	+
HRPM	x	x	+	+					
IoT	1. x	x	+	+	+				x
Smart Factory	x	x	x		x	x	+	x	+
CPPS	x	x	x	+		2. x	x	x	
Smart Production Systems		x	x	x	x	x	x	x	+
Cloud Computing		4. x	x	x	x	x	+		
Mobile Technology	x	x	+	+	+		+	+	x
	Legend: x Strong correlation; + Weak correlation								

Using Table 3-2, the VMS model is extended to include the PRITA system or systems that was clustered according to their functionality through strong correlations functionality adhering tendencies. By accomplishing this, the four elements of the VMS model, now have four corresponding information sourcing and handling systems support model as summarised in Table 3-3.

Table 3-3: Function grouping according to PRITA and VMS analysis

1	**Function**	**PRITA**	**VMS Element**
	Single or Multiple data inputs.	HRPM	Visualization Tool
	Data sourcing and clustering		
	Data processing		
	Visualization		
2	**Function**	**PRITA**	**VMS Element**
	Intelligence	Smart Production Systems	Smart Processing
	KPI generation		
	Production Related Information		
	Visualization		
	Data processing		
	Data storing		
3	**Function**	**PRITA**	**VMS Element**
	Single or Multiple data inputs.	Automation Pyramid	User Spesific Information
	Data sourcing and clustering		
	Data processing		
	Security and Communication		
	Production Related Information		
4	**Function**	**PRITA**	**VMS Element**
	Single or Multiple data inputs.	Mobile Technology and Cloud Computing	Mobile Technologies
	Data sourcing and clustering		
	Data processing		
	Data storing		
	Security and Communication		

The first PRITA systems cluster that can provide the necessary data sourcing from single or multiple sources whilst providing clustering and processing of data in order to yield the visualisation tool are the following: HRPM, IoT and Smart Factory. Owing to VMS's need to have various sources of data, these three systems can be clustered together to provide the solution. By definition, the HRPM describes the method of having various input sources and was, therefore, chosen to be the main PRITA system that would support VMS with visualization tools where IoT and SF technology are the supporting systems. Here, IoT is considered for its ability to produce the output of information on an online platform while the SF provides the production environment in which this VMS element can be installed.

The second cluster focusses on intelligence, KPI generation and production knowledge incorporation. Once the correlation study was completed, three PRITAs became apparent, namely SF, CPPS and Smart Production Systems. All three PRITA systems focus on production processing, the quick changeover ability, and improved scheduling and control. They could also provide the functions of data sourcing and processing in the production environment, thus, provide support for the second VMS element, which is smart data processing. This ability is important in order to produce information that provides feedback on the production environment.

The third cluster only includes the automation pyramid PRITA, but incorporates multiple functions. The automation pyramid's architecture provides the necessary foundation for all types of data sourcing, processing from multiple sources, and the ability for secure communication of data and digital storing of information solutions between three distinguishable levels of operation, specifically ERP, MES and shop floor level. It was, therefore, useful to correlate this PRITA with the third VMS element that provides user specific information due to its three levels managerial architecture within the operation and management framework that breaks down the communication protocols within a manufacturing organisation.

The fourth element of VMS is mobile technologies. Thus, the last cluster of functionalities coincides with the necessary PRITAs to support mobile technologies, cloud computing and SF functionalities. Mobile technologies provide the convenient and instantaneous information access support for VMS.

The VMS model can thus be updated to incorporate the corresponding PRITAs of each VMS element and can be seen in Figure 3-5 below.

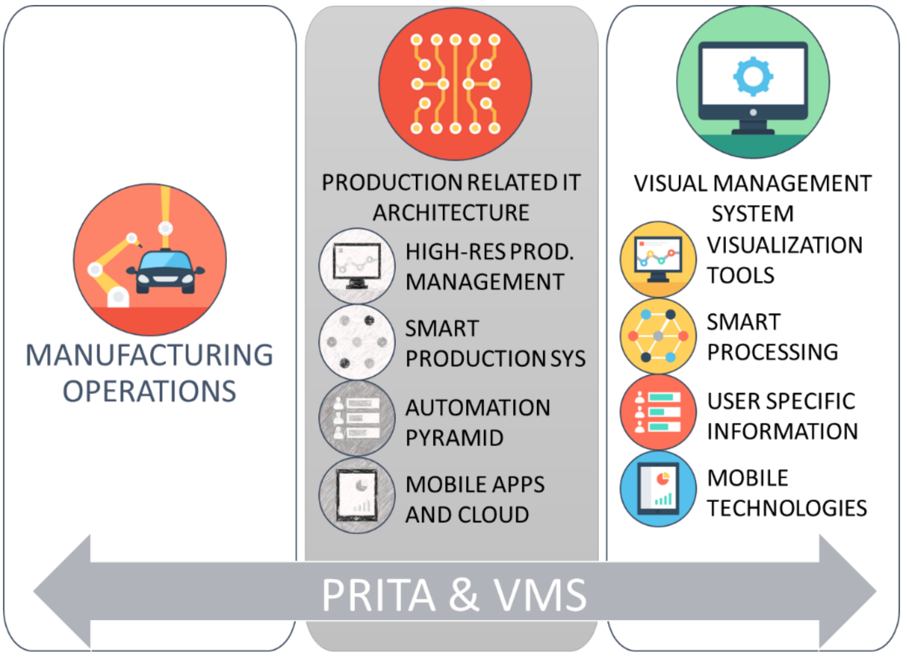


Figure 3-5: Proposed PRITA and VMS model

3.3.3 *Example*

Figure 3-6, illustrates an example of the collection of systems, their corresponding functions and the correlation or co-dependency to each other. From left to right, the PRITAs connects to the systems that can perform these IT-related VMS functions. After completing the correlation test of Table 3-3, Figure 3-6 was created to demonstrate the first VMS model element (visualization tools) and how the different functions of VMS and PRITA models are connected to produce a process of data and information flow. In doing so, deconstructs the black-box to input-output elements thereof.

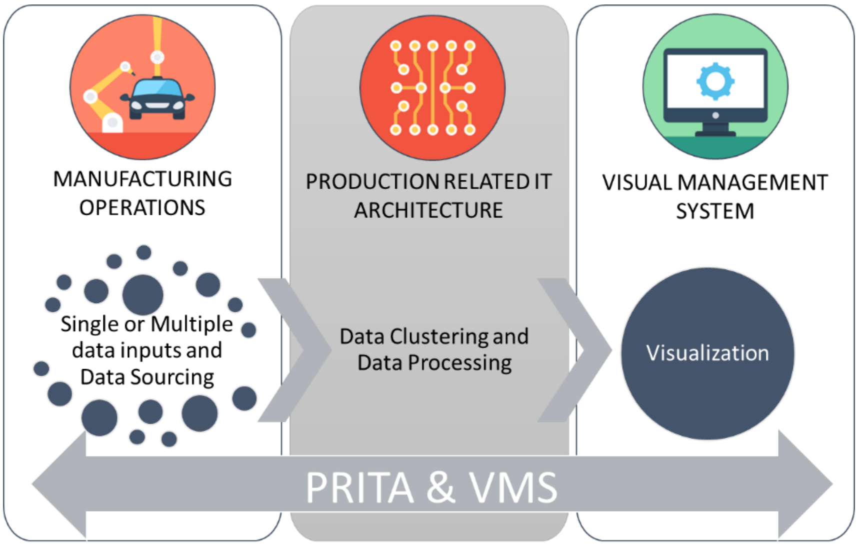


Figure 3-6: Prototypical VMS and PRITA Example of first VMS element: Visualisation Tools

In the prototypical example representing the first element of the VMS model in Figure 3-6, the process of data sourcing from manufacturing operations, clustered and processed with PRITA and then visualized with VMS, is represented. This demonstrates the process in principle of creating presentable information from different production process' data sources.

The design and engineering activities that will be discussed in the next section are necessary to demonstrate the extent of the activities and functions of PRITAs. These functions provide the foundation for implementation and starting point to add functions within the IT production systems of VMS. It also provides a breakdown of elements that need focus during the design and implementation phase of PRITA integration.

3.3.4 *System Operational Requirements*

The process planning is necessary to develop a systematic sequence of data gathering, processing and accessing from multiple sources throughout the entire company. To accomplish this feat, the value stream of the organisation can be investigated as a foundation in order to determine the possibilities of data sourcing and data accessing points in the value stream of production. These points will then become the points where either new data is added or processed for accessing VMS. The need for appropriate data collection definition that correlates to the sources of data is addressed in this section. This eases the processing phase and turns the data into processed information for access by VMS. Here, the requirements are discussed in the sequence starting with historical data for trend comparison, shop floor data collection and processing, data communication and storage, ERP, MES and decision-making, time and resource management, IoT technical applications, standardization and the security measures.

Historical data is information outlining activity, conditions and trends in a company's past. Historical data is important to spot trends throughout the company's history in order to predict future expansion or improvement opportunities. These data sets can be collected from the entire company or different factories within the manufacturing industry. Data can include the process maps and jobs currently in progress, logistical data from pickup and deliveries, machine conditions, efficiency and maintenance updates, the labour distribution, productivity and efficiency, projects assigned, schedules and so forth. Other data may include the stock in storage/warehouse and the amount of inventory left, PLC's operation logs, environmental monitoring devices, IoT monitoring technologies, and any other sensing, monitoring or data gathering devices with limited or no processing capabilities.

Digital data storage consists of computer memory hardware and online databases used to save digital data. These data storage devices connect to a server that distributes the data and functions as the centre for communication infrastructure. The server's task is to allocate storage for data on the database for information that the organisation wishes to keep. Technically, within a SF environment, everything should have some degree of intelligent data producing technology. They should also be connected to a central communication that can consist of Wi-Fi, LAN, Bluetooth or RFID communication protocols. However, considering the lack of standardization and the enormity of the scope of heterogeneous information produced, the solution to cope with this is not yet been fully addressed.

Managerial inputs (ERP, MES and shop floor management) need to be gathered in order to accommodate quick and real updates of current activities. These types of inputs can improve transparency in the decision-making process regarding production within an organisation. The gathered information would improve the understanding of choices made by other managerial positions and, therefore, improve overall company effective behaviour. New and current project information must be documented and with these information scheduling and control techniques can be applied at the ERP and MES levels to contribute to projects completion rate. Such information could also be incorporated in the processing aspect of the VMS for easy access.

Slack, down-time, breakdowns, bottlenecks, component shortages, late orders, urgent projects or other constraints within the production planning can provide quality information for responsive scheduling and control options. The VMS can enable this vital measure, where the transparency of information can supply the decision-maker with enough relevant information to make an informed decision.

Another issue that is addressed frequently in the literature is the security measures that should be put in place to facilitate secure information exchange in the organisation. This requirement, together with the above mentioned communication protocol and IT infrastructure, are the main reason for the slow implementation of IoT technologies within production processes. Literature indicates that communication, security and data handling, sourcing and processing in PRITAs are problematic owing to the lack of standardization of implementation or architecture to date. Other systems that would need attention are the operations of every element that will gather data from its working source and combine the different interfaces on a universal platform. To circumvent this problem, a data collection process consisting of IoT and related technologies to communicate on a secure network and process data on a universal platform is suggested. This provides the opportunity to add new technological advancements or expansion to the system when required. The universal platform should, therefore, be stable and designed for future extensions.

3.4 Case Studies

3.4.1 *Overview*

Manual visual management tools have formed part of industrial information representation for decades, showing schedules, project layout, priority classification, and job deconstructions [66]. To keep up with modernisation of the industry, we are now moving into an ever increasing digital age where the information collection comes from multiple and heterogeneous sources [13], [60]. This section discusses how four case studies were developed to investigate the VMS model. Details of the model and the case studies can be seen in Figure 3-7.

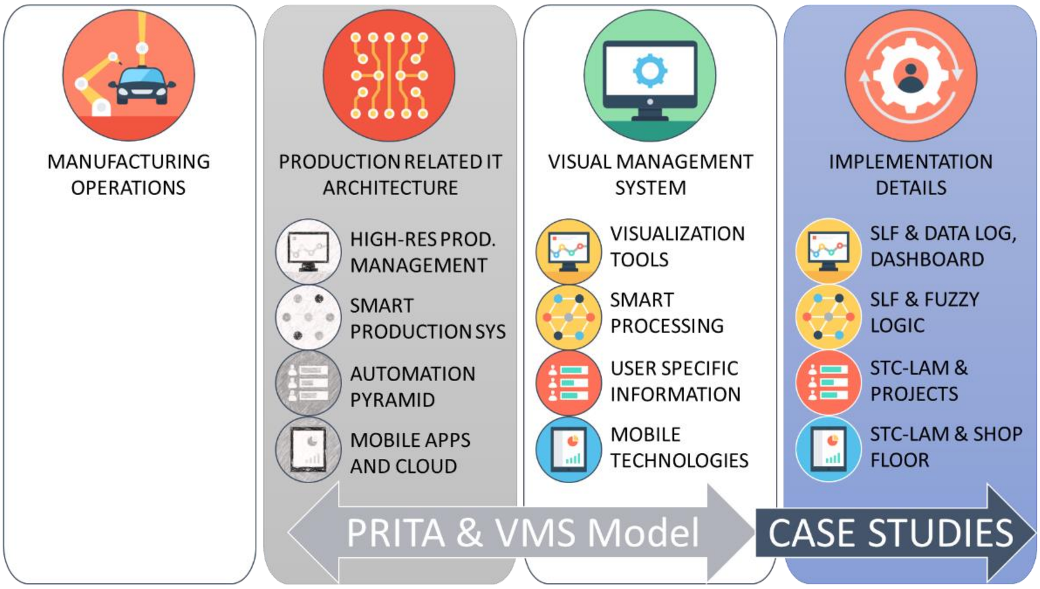


Figure 3-7: PRITA and VMS Case Studies Details

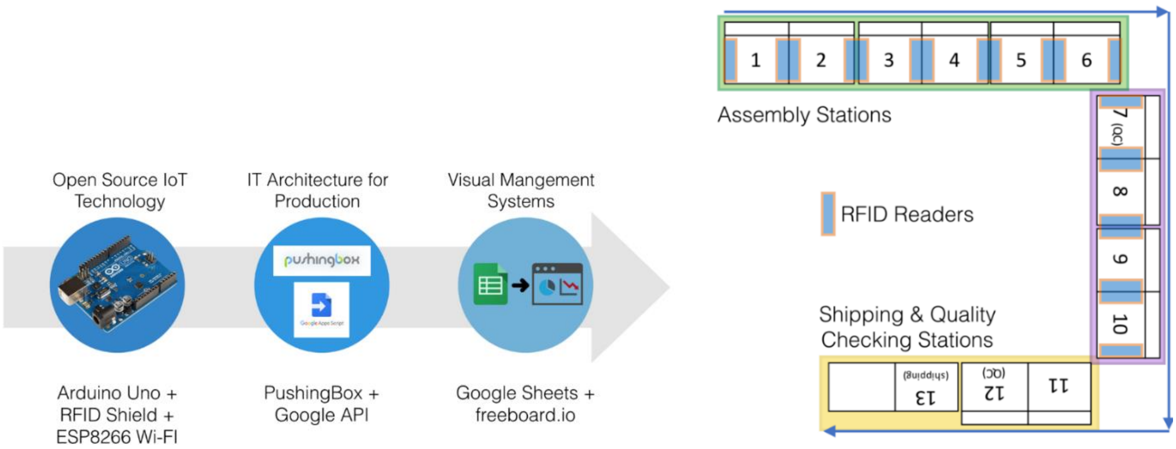
In this section, four PRITA systems will support the implementation requirements of VMS with case studies in order to investigate their implementation capabilities. The objective of this section is to determine possible implementation application for VMS elements based on the model. The results are validated based on how well they perform their tasks and in doing so investigate the effects and benefits of the PRITA and VMS model. The section also explains the process of incorporating four PRITAs (automation pyramid, high-resolution production management, smart production systems and mobile technologies) into the manufacturing environment and the effects the subsequent VMS has on operations.

3.4.2 *High Resolution Production Management*

South Africa has a wide variety of problems that range from unreliable electricity supply to low skill level and low productivity levels of the south African manufacturing industry workers [31], [37]. This section investigates the latter, and how VMS can improve productivity and resource management by methods of information communication. This section details the development and implementation activities of a HRPM system within the Stellenbosch Learning Factory (SLF) to investigate the effective use of KPI dashboards to communicate information. The focus of which will be to investigate sourcing, processing data straight from the shop floor and then using visualization tools to communicate information to workers or managers with a split second delay. For this case study, IoT technology was introduced within the SLF to support the development of this HRPM system. The process therefore required a cheap, sustainable and user friendly solution with the focus on communicating valuable production control and scheduling information. This PRITA provides the necessary functions to source and cluster heterogeneous data together required by a VMS.

The SLF is an academic teaching tool that provides a mock manufacturing environment in which model trains are build. It is designed to resemble a typical South African SME within the manufacturing industry to teach logistic and lean tools. It consists of multiple assembly workstations in a process chain configuration together with a quality check, order, delivery and rework stations and the layout can be seen in Figure 3-8. The SLF can therefore be used to investigate the implementation of a VMS and the effects it can have on presenting production information using visualisation tools. The methodology of this case study implementation therefore consisted of an investigation and understanding the scope of the problem within the South African context: to make the information presentable in such a way for easy and fast information comprehension for low skilled workers, and to investigation possible open source or freeware solutions. Followed by development of these solution within the SLF to determine quantifiable KPI to be displayed on visualization tools and dashboards corresponding with the first element of the VMS model.

The process of determining the KPIs that could be captured by a HRPM system within the SLF was then broken down into a two-part problem. The first was what vital KPIs of the production process can improve the production transparency and where can data be collected to support these KPIs [9], [13], [29], [95]. The second was how can this data be sourced from the production line and what IoT can be used to produce the solution [17], [39]. The IoT technology and layout of the SLF can be seen in Figure 3-8. Workstation 3 is used for its long cycle time of sixty-nine seconds (was rounded up to seventy seconds for simplification). The SLF provides a functional production line that simulates that of manufacturing SMEs in the surrounding area. There are no current IoT or smart production systems implemented in the SLF.



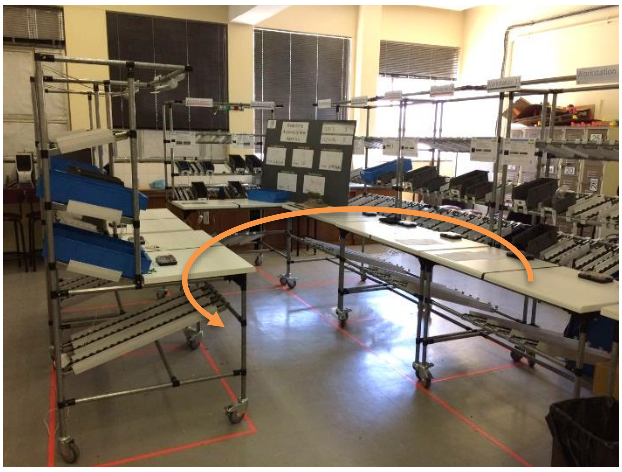
(a) *(b)*

Figure 3-8: SLF (a) IoT technology and (b) layout of workstations

Two SLF KPIs became apparent to display on a dashboard whilst being easy to source and process in real time using IoT technology. They are uptime percentage and productivity of the production line. Uptime percentages are calculated using the time of active production time divided by the entire shift time of production and provides an indication of how well time is being utilized. The second KPI, productivity, is a function of finished products over the total products that went through the production line and focusses on monitoring the amount of faults in production with regards to the rework and/or scrap count.

The second problem was addressed with the development and implementation of a data logger device that uses RFID scanner and tags, and communicates data to an online database over Wi-Fi. This is necessary for a central processing and information distribution platform for the visualization element. The hardware consisted of an Arduino UNO microprocessor, an AdaFruit RFID scanner and an ESP8266 Wi-Fi module [102]. The timestamp and RFID tag data was collected by the RFID scanner when a work-in-progress container enters and exits a workstation which indicates that a workstation would require two RFID scanners.

The goal is to investigate the implemented data logger and see if one could source the necessary data sets to produce the prescribed KPIs. The process of how the data collection process happened was as follows: First, the containers that held the model train as it passes through the production line was fitted with an RFID tag. This container goes through the production line, being passed on from one station to the next until the last workstation where the container will hold a fully assembled model train. This container with the RFID tag can then be used to track the work-in-progress data as it moves from workstation to the next by collecting data at the entry and exit point of the workstation. Therefore, the RFID scanner positioning needs to be at the first station as the empty container enters the production line, then between stations at every point where the container is presented to the next workstation, and finally at the last workstation as the container with the finished product is transferred to the shipping and quality check station. To explore this case study in concept. One data logger was developed and implemented on workstation 3 to collect the timestamp and RFID tag data set of the container. This data logger is capable of sending data to the Google Sheet online database with a constant two-second delay. Pictures of data logger, workstation layout and RFID scanner and tags can be seen in Figure 3-9 (see Appendix A for instruction on how to build the data logger).



(a)

(b)

(c)

(d)

Figure 3-9: SLF (a) production line layout, (b) 1. container, 2. RFID tag and 3. data logger installed on WS 3, (c) container passing past the RFID scanner between WS 2 and 3 and (d) technology components of data logger.

In a previous investigating completed by the SLF development team, a line-balancing time study was performed on each of the workstations and the results of each assembly time of each step can be seen in Table 3-4. From this study, data of workstation 3 was generated with the objective to create the KPIs of processed information for dashboard creation and can be seen in Table 3-5. This data of workstation 3, input and output times and RFID UID, was captured in an online Google Sheet database in which the clustering and processing of data to determine the production line KPIs was completed and displayed on a digital dashboard using the same platform [103], [104].

Table 3-4: SLF Variant 2 - Round 1 assembly times sheet

Workstation	Assembly part	Assembly step	Amount of Screws	Time per step in min	Total Time in min
1	1st side plate	Screw to the base plate	4	0:50	0:50
2	1st face plate	Screw to side plate	1	0:36	0:36
3	divider	Screw to 1st side plate	2	0:24	
	divider	Screw to 1st side plate	2	0:12	
	divider	Screw to 1st side plate	2	0:11	
	2nd face plate	Screw to 1st side plate	2	0:22	1:09
4	2nd side plate	Screw to the base plate	4	0:33	
	2nd side plate	Fix the rest of the screws	8	1:07	1:40
5	right seat row (narrow)	Put in seats		0:35	0:35
6	left seat row (wide)	Put in seats		0:32	0:32
7	QC - interior	Checks the seats and dividers		0:15	0:15
8	Roof	Screw on the roof	2	0:22	0:22
9	Electrical system	Screw it in to the front position	2	0:26	0:26
10	Pump system	Screw it in to the back position	2	0:24	0:24
11	Bogie	Screw on (transparent washer - bogie - washer - screw)	1	0:25	
	Bogie	Screw on (transparent washer - bogie - washer - screw)	1	0:25	0:50
12	QC - exterior	Visual check: screws, layout of electrical and pump system,	1	0:30	0:30
13	Shipment	Put train in box and label it	1	0:30	0:30
			Total time model train assembly		**8:39**

Table 3-5: SLF production line data processing

Timestamp	RFID UID	Total working tim	Total waiting Time	Uptime Persentage	Cycle Time Deviation	Completion Coun	Total Faults	Production
4/7/2016 14:01:54	302	0:00:00	0:00:02	0,00%	0,00%	0	0	0,00%
4/7/2016 14:03:14	302	0:01:20	0:00:02	97.50%	-0,01%	1	0	100,00%
4/7/2016 14:03:19	477	0:01:20	0:00:05	93,75%	-0,01%	1	0	100,00%
4/7/2016 14:04:24	477	0:02:25	0:00:05	96,55%	0,01%	2	0	100,00%
4/7/2016 14:04:27	507	0:02:25	0:00:08	94,48%	0,01%	2	0	100,00%
4/7/2016 14:05:24	507	0:03:22	0:00:08	96,04%	0,02%	3	0	100,00%
4/7/2016 14:05:25	687	0:03:22	0:00:09	95,54%	0,02%	3	0	100,00%
4/7/2016 14:06:54	687	0:04:51	0:00:09	96,91%	-0,02%	4	0	100,00%
4/7/2016 14:06:59	777	0:04:51	0:00:14	95,19%	-0,02%	4	0	100,00%
4/7/2016 14:07:54	404	0:05:46	0:00:14	95,95%	0,02%	4	1	80,00%
4/7/2016 14:07:57	892	0:05:46	0:00:17	95,09%	0,02%	4	1	80,00%
4/7/2016 14:09:09	892	0:06:58	0:00:17	95,93%	0,00%	5	1	83,33%
4/7/2016 14:09:12	957	0:06:58	0:00:20	95,22%	0,00%	5	1	83,33%
4/7/2016 14:09:54	957	0:07:40	0:00:20	95,65%	0,03%	6	1	85,71%
4/7/2016 14:09:56	102	0:07:40	0:00:22	95,22%	0,03%	6	1	85,71%
4/7/2016 14:10:54	303	0:08:38	0:00:22	95,75%	0,01%	6	2	75,00%
4/7/2016 14:10:57	247	0:08:38	0:00:25	95,17%	0,01%	6	2	75,00%
4/7/2016 14:12:14	247	0:09:55	0:00:25	95,80%	-0,01%	7	2	77,78%
4/7/2016 14:12:19	302	0:09:55	0:00:30	94,96%	-0,01%	7	2	77,78%
4/7/2016 14:13:34	302	0:11:10	0:00:30	95,52%	-0,01%	8	2	80,00%
4/7/2016 14:13:42	477	0:11:10	0:00:38	94,33%	-0,01%	8	2	80,00%
4/7/2016 14:14:38	477	0:12:06	0:00:38	94,77%	0,02%	9	2	81,82%
4/7/2016 14:14:43	507	0:12:06	0:00:43	94,08%	0,02%	9	2	81,82%
4/7/2016 14:15:54	507	0:13:17	0:00:43	94,60%	0,00%	10	2	83,33%
4/7/2016 14:15:55	687	0:13:17	0:00:44	94,48%	0,00%	10	2	83,33%
4/7/2016 14:16:54	687	0:14:16	0:00:44	94,86%	0,01%	11	2	84,62%

The data sets of workstation 3 that can be seen in Table 3-5, was generated with the use of simulation of the production line and not an actual production line run. The reason for this was due to the robustness of the data logger not meeting industrial grade operation requirements and could therefore only served as a proof of concept of operation. The data logger was capable of posting data accurately to Google Sheets, but unfortunately, lacked consistency. It was capable of capturing almost all the product UID and timestamp data set passing past the RFID scanner on the workstation, but due to the Wi-Fi module, communication between the data logger and the online database was sometimes interrupted causing it to miss a tag and timestamp of a product. This led to incomplete data set, which in turn produced an incorrect information within the database and influencing the dashboard KPIs. It was therefore decided to make use of generated data to conceptually support the validation process of the visualisation element of VMS.

A visualization dashboard was then created that displays the uptime percentage, the cycle time deviation, scrap and rework count and productivity of workstation 3 and can be seen in Figure 3-10. The dashboard captured the processed data of eleven model trains that were successfully completed, one that was moved to a rework station and one that was scrapped, for a total of thirteen commissioned model trains. The method of capturing the number of the rework of scrap whilst still in the production line was achieved by introducing two extra RFID tags into the production line. These two cards were reprogrammed to have to two Unique Identifiers (UIDs) that where numbers 303 and 404. These cards were incorporated to introduce fault count into the production line and represents rework and scrap errors respectively. They will be used after the work-in-progress container enters the workstation area and a decision is made to remove it from the production line based inspection of the condition of the work-in-progress model train and its current assembly status. They will then use one of the fault cards to swipe the container out at the exit data logger, before the container is taken out of the production line to the rework or scrap station. The 303 UID donating that the current work-in-progress container that has entered the workstation classifies as need a rework and 404 UID denotes that the product can be scrapped for salvageable parts. The reason for this system is the necessary for producing two timestamp and RFID tag data sets. The first will be the enter data set of the container coming into the workstation and the second can swipe out the product from the workstation, thus providing the initial product ID, the error code and the timestamps of this product

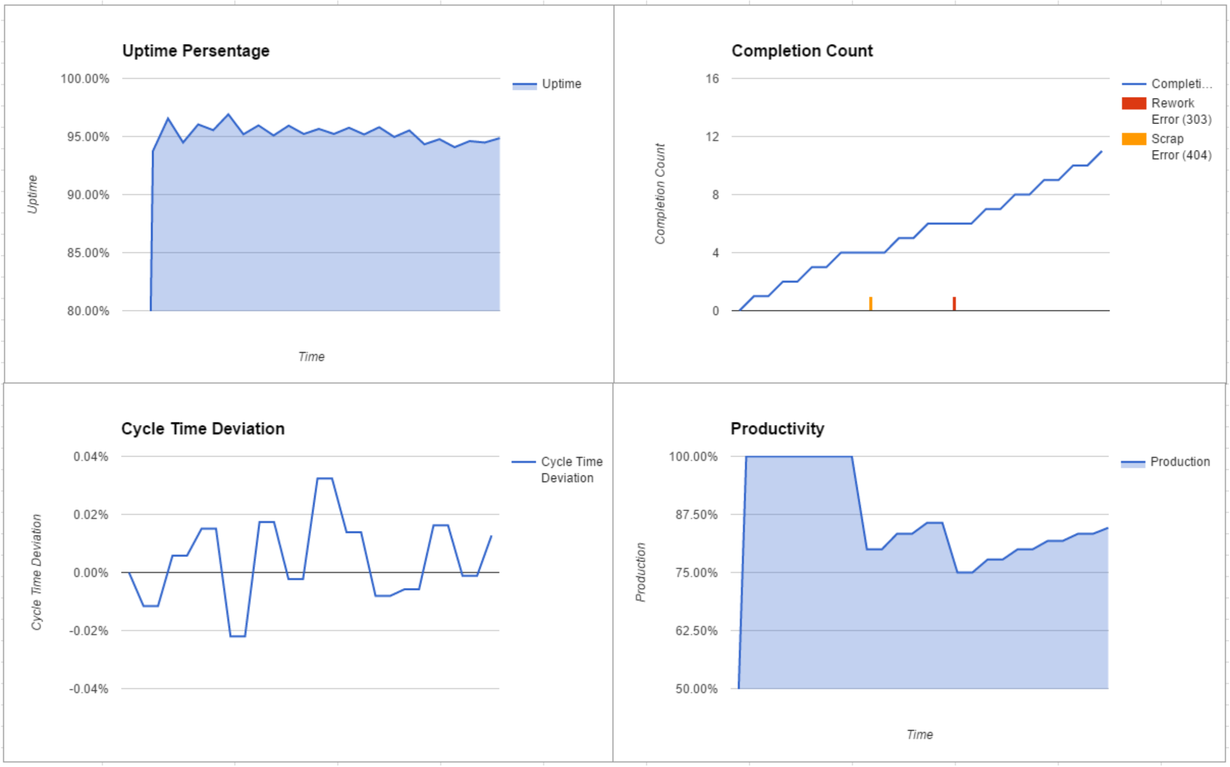


Figure 3-10: SLF KPI Dashboard

The productivity as seen in Figure 3-10 is influenced by the rework and scrap count. The correlation between these graphs are that the productivity is a function of the total completed products and the scrap and reworks. In Figure 3-10, the first four products where products that was completed without any issues, then one was removed for rework, then two was completed, followed by a scrap case. These cases then also provide with the cycle time to produce cycle time deviations. The cycle time deviation chart, that can also be seen in Figure 3-10, is a representation of deviation time in percentage from the seventy second per product benchmark that represent the zero percent line.

For the validation of this case study, a questionnaire was send out to the research group as part of the longitudinal research method (see Appendix B for a copy of the questionnaire). The questionnaire consists of a pre- and post-opinion collection. The participants were, therefore, given more information as the questionnaire progresses with the same questioned asked at different stages and/or focus on the same variables throughout this study. The objectives of this questionnaire were to:

1. Determine the effectiveness of using visual management systems to relate production information, and
2. To determine the level of comprehension achieved by the participants or to investigate how quickly and easily they can relate to the information presented.

The first and last questions are directed at the participants to evaluate the importance of the dashboard of workstation 3 and validate the VMS visualisation tool element. The question asked here is: Do you think it is important to have visual management systems in the workplace? The predefined responses were: not important, not really important, neutral, somewhat importance, and very important. The data captured before and after the questionnaire is presented in Figure 3-11.

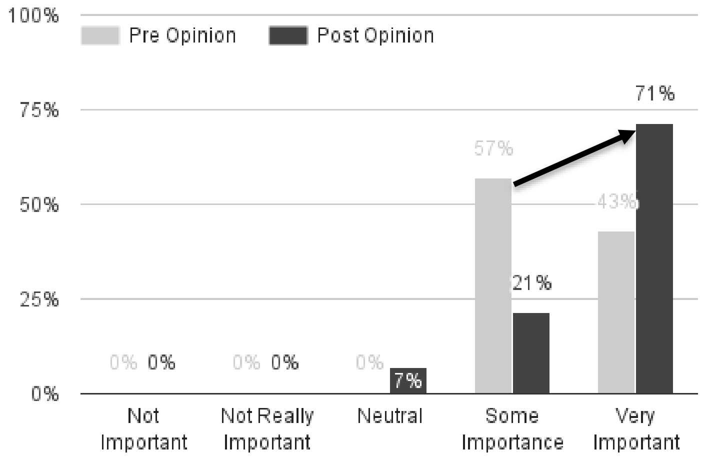


Figure 3-11: SLF validation of VMS's Importance

Before completing the questionnaire, the participants believed that a VMS, similar to that implemented on Workstation 3, was important but not a necessity, with 57% of the participants saying it is somewhat important. After being introduced to VMS and the dashboard on workstation 3, their opinion on its importance changed. The participant's overall opinion improved to 71% agreeing that it is very important. This then concluded the first objective of this study.

The second objective was to determine if the level of comprehension levels increased before and after introduction to the dashboard on workstation 3. In this case the raw tabled information was presented to them in the form of a spreadsheet with the question: Would you say that you can understand the data representation to the following degree: nothing, some, neutral, most or everything. The information is then presented to the participants using a dashboard and the same question is asked once more. The results are displayed in Figure 3-12 and discussed following the figure.

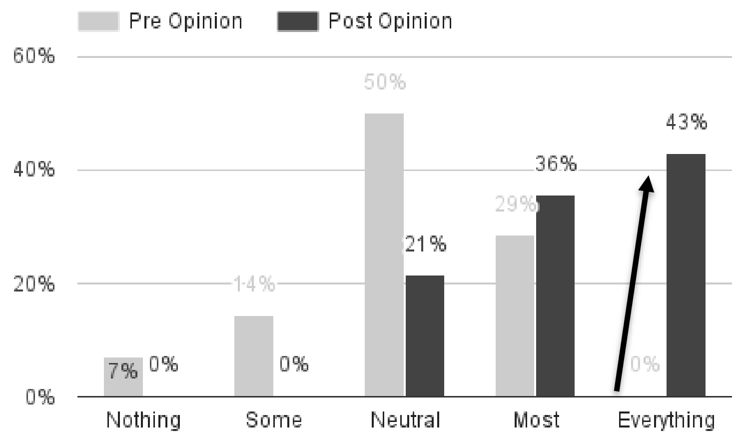


Figure 3-12: SLF validation of VMS comprehension level.

The figure shows that the majority of participants' level of data comprehension increases comprehension levels. Again, the interpretation for this effect is caused by the participants' ability to understand easily and more rapidly the data presented by VMS when using visualization tools. Thus, achieving the second goal of this validation with a 43% increase in understanding all the data presented with the dashboard on workstation 3.

This prototypical study outlines a methodological approach to investigating VMS in SMEs, in a South African context with scarce funding and low levels of technological maturity. The SLF provides an opportunity to investigate the use of the IoT and its associated technologies in such an environment. The case study that involved the data logging of the products assembled on the workstations yielded information that is visually represented on an online dashboard. Future work would involve the expansion of the KPIs through enhanced data collection methods.

3.4.3 *Smart Production Systems*

The case study in the previous section discussed in detail the process of creating the VMS in the SLF and provided the foundation for further expansion. The dashboard deployed in SLF incorporates visualization tools for displaying the uptime, cycle time deviation, rework and scrap count, and the productivity of the production line. Although these are important production KPIs, a question could be posed as to whether the collected data could be used to determine if the amount of products requested would be finished in time? Smart production system is a term used to indicate a certain level of intelligence incorporated into the production activity. Where CPPS focusses on creating a virtual counterpart of the physical production environment, smart production systems can incorporate intelligence together with production knowledge in order to improve data analytics. The VMS can then communicate the information to the user.

In this case study, the same data that is produced by Workstation 3’s production line (of the previous case study) is used. The focus, however, shifts to determining if the production process is going to be finished on time using the data presented. This case study, therefor, investigates the possibility of trend spotting, which assists the users in the decision-making process. Fuzzy logic is introduced in order to determine the possibility of on-time completion. The same method is used in a similar case study conducted by Araniba (1994) [82].

Fuzzy logic is a form of many-valued logic. In this study, fuzzy logic is specifically considering the cycle time of the production process and if it is in the bounds of producing the amount at the desired rate. The conditions of finish, thus ‘Definitely yes’, ‘Maybe’ and ‘Definitely no’ are used as linguistic variables to indicate the completion condition relating to finishing on time. Both the cycle time deviation and fault count will be incorporated in the fuzzy logic model, thus, providing two sets of rules as shown in Figure 3-13. Note that the scrap and rework count will from this point forward be addressed collectively as the fault count.

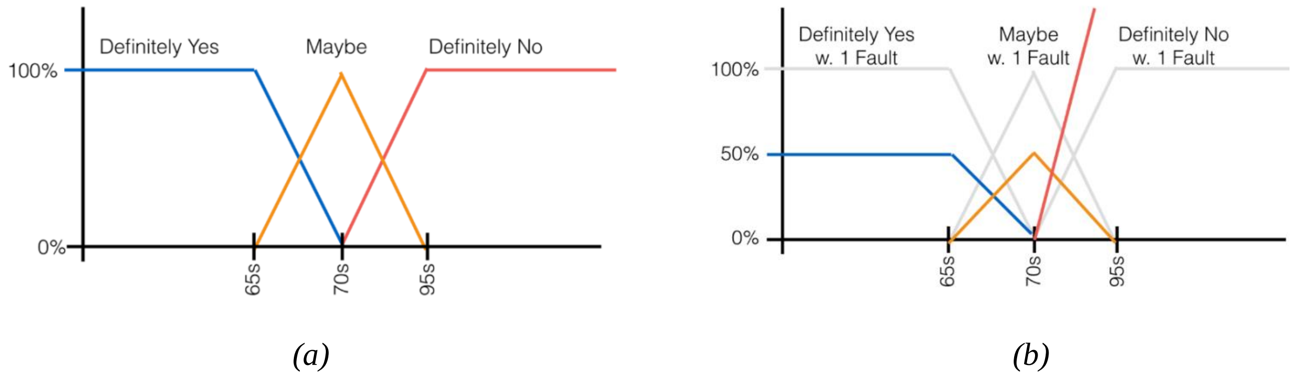


Figure 3-13: Fuzzy logic incorporating (a) cycle time and adding (b) fault numbers

The two figures above represent two sets of rules of which the first focusses on the cycle time of each product and groups them into three fifteen second intervals. The seventy-second cycle time was achieved by a benchmark test produced with a Method-Time Measurement (MTM) study of a breakdown of the assembling activities on workstation 3 and was determined by the SLF development team. The other two conditions are then spaced fifteen seconds interval away from this benchmark. The last increment would, therefore, imply that the production is definitely late and the first would indicate that production is on time., presenting a slow or fast production cycle rate respectively.

The second rule of Figure 3-13 illustrates the fault count rule and is also incorporated within the fuzzy logic rule set. The concept behind this rule is to demonstrate and investigate the effect of having to remove products from the production line due to rework or scrap errors. The effects on the linguistic variables of the completion rate will now be impacted by a factor that is indirectly related to the amount of faults in production for the condition ‘definitely yes’, and ‘maybe’, while the condition, ‘definitely no’, will be in direct relation to the amount of faults.

Mathematically, the first rule is determinable with the use of Equations 1 to Equation 3, where *t* represents the cycle time and *P* is the percentage of the quantitative fuzzy logic output between definitely yes, maybe and definitely no.

$$P_{Yes} = \begin{cases} 100\% & if\ t \leq 65s \\ \left(\frac{70s-t}{70s-65s}\right) * 100\% & if\ 65 > t > 70s \end{cases} \qquad [1]$$

$$P_{Maybe} = \begin{cases} \left(\left(\frac{70s-t}{70s-65s}\right) - 1\right) * 100\% & if\ 65 > t > 70s \\ \left(\frac{95s-t}{95s-70s}\right) * 100\% & if\ 70 > t > 95 \end{cases} \qquad [2]$$

$$P_{No} = \begin{cases} \left(\frac{95s - t}{95s - 70s} - 1\right) * 100\% & if\ 70 > t > 95s \\ 100\% & if\ t \geq 95 \end{cases} \quad [3]$$

The second rule incorporates the fault count of the production process. This rule indicates that for each product that was faulty, the quantitative percentage of production being on time, is halved, making this rule indirectly proportionate to the fault count and mathematically determinable with Equation 4. In this equation, the percentage that is calculated in Equation 1 to Equation 3 will be put through the following equation where *N* represents the fault count:

$$P_{new} = \begin{cases} \left(\frac{P_{old}}{N_{Fault}+1}\right) & if\ P_{old} = \begin{cases} P_{Yes} \\ P_{Maybe} \end{cases} \\ P_{old} * (N_{Fault} + 1) & if\ P_{old} = P_{No} \end{cases} \quad [4]$$

The results of the case study are captured with two cases. The first case was a perfect run where the scrap and rework count is ignored. The second study incorporating the same data set, but reintroducing the fault count data, thus, making these two cases comparable according to the longitudinal research method. The first case's data is captured in Table 3-6 and Figure 3-14 showing the dashboard of no faults in the production line.

Table 3-6: SLF's smart dashboard showing first case tabled data

Product	Condition	Time	Cycle Time	Fuzzy Rule 1: Cycle Time Deviation	Total Faults	Fuzzy Rule 2: Fault Count Factor	Definitely yes	Maybe	Definitely not
1st	Start Time	2:01:54 PM	0:00:02	0:00:00	0	1,00	33,00%	33,00%	34,00%
1st	Finish Time	2:03:14 PM	0:01:20	0:00:10	0	1,00	34,58%	27,10%	38,40%
2nd	Start Time	2:03:19 PM	0:00:05	0:00:10	0	1,00	35,16%	27,75%	37,20%
2nd	Finish Time	2:04:24 PM	0:01:05	-0:00:05	0	1,00	35,75%	28,40%	36,00%
3rd	Start Time	2:04:27 PM	0:00:03	-0:00:05	0	1,00	36,34%	29,05%	34,80%
3rd	Finish Time	2:05:24 PM	0:00:57	-0:00:13	0	1,00	36,93%	29,70%	33,60%
4th	Start Time	2:05:25 PM	0:00:01	-0:00:13	0	1,00	37,51%	30,35%	32,40%
4th	Finish Time	2:06:54 PM	0:01:29	0:00:19	0	1,00	38,10%	31,00%	31,20%
5th	Start Time	2:06:59 PM	0:00:05	0:00:19	0	1,00	38,69%	31,65%	30,00%
5th	Finish Time	2:07:54 PM	0:00:55	-0:00:15	0	1,00	39,28%	32,31%	28,80%
6th	Start Time	2:07:57 PM	0:00:03	-0:00:15	0	1,00	39,87%	32,96%	27,60%
6th	Finish Time	2:09:09 PM	0:01:12	0:00:02	0	1,00	40,45%	33,61%	26,40%
7th	Start Time	2:09:12 PM	0:00:03	0:00:02	0	1,00	41,04%	34,26%	25,20%
7th	Finish Time	2:09:54 PM	0:00:42	-0:00:28	0	1,00	41,63%	34,91%	24,00%
8th	Start Time	2:09:56 PM	0:00:02	-0:00:28	0	1,00	42,22%	35,56%	22,80%
8th	Finish Time	2:10:54 PM	0:00:58	-0:00:12	0	1,00	42,80%	36,21%	21,60%
9th	Start Time	2:10:57 PM	0:00:03	-0:00:12	0	1,00	43,39%	36,86%	20,40%
9th	Finish Time	2:12:14 PM	0:01:17	0:00:07	0	1,00	43,98%	37,51%	19,20%
10th	Start Time	2:12:19 PM	0:00:05	0:00:07	0	1,00	44,57%	38,16%	18,00%
10th	Finish Time	2:13:34 PM	0:01:15	0:00:05	0	1,00	45,16%	38,81%	16,80%
11th	Start Time	2:13:42 PM	0:00:08	0:00:05	0	1,00	45,74%	39,46%	15,60%
11th	Finish Time	2:14:38 PM	0:00:56	-0:00:14	0	1,00	46,33%	40,11%	14,40%
12th	Start Time	2:14:43 PM	0:00:05	-0:00:14	0	1,00	46,92%	40,76%	13,20%
12th	Finish Time	2:15:54 PM	0:01:11	0:00:01	0	1,00	47,51%	41,41%	12,00%
13th	Start Time	2:15:55 PM	0:00:01	0:00:01	0	1,00	48,10%	42,06%	10,80%
13th	Finish Time	2:16:54 PM	0:00:59	-0:00:11	0	1,00	48,68%	42,71%	9,60%

In Table 3-6 there are two data sets that needs addressing. The first is the use of start and finish time to produce the cycle time of each product needed for the fuzzy logic algorithm's first rule. The cycle time of each product is then compared to the cycle time benchmark of seventy seconds to produce the deviation time. This deviation time is then introduced to Equation 1 to 3 to calculate the production process condition of 'definitely yes', 'maybe' and 'definitely no' in percentages. The second data set that needs explaining is the second rule of the fuzzy logic algorithm. This rule demonstrates the indirect relationship between fault count and the fault count fuzzy logic factor. For the first case fault count was ignored and therefore the factor was constant at one. The second rule will be explained after the second comparative study is introduced.

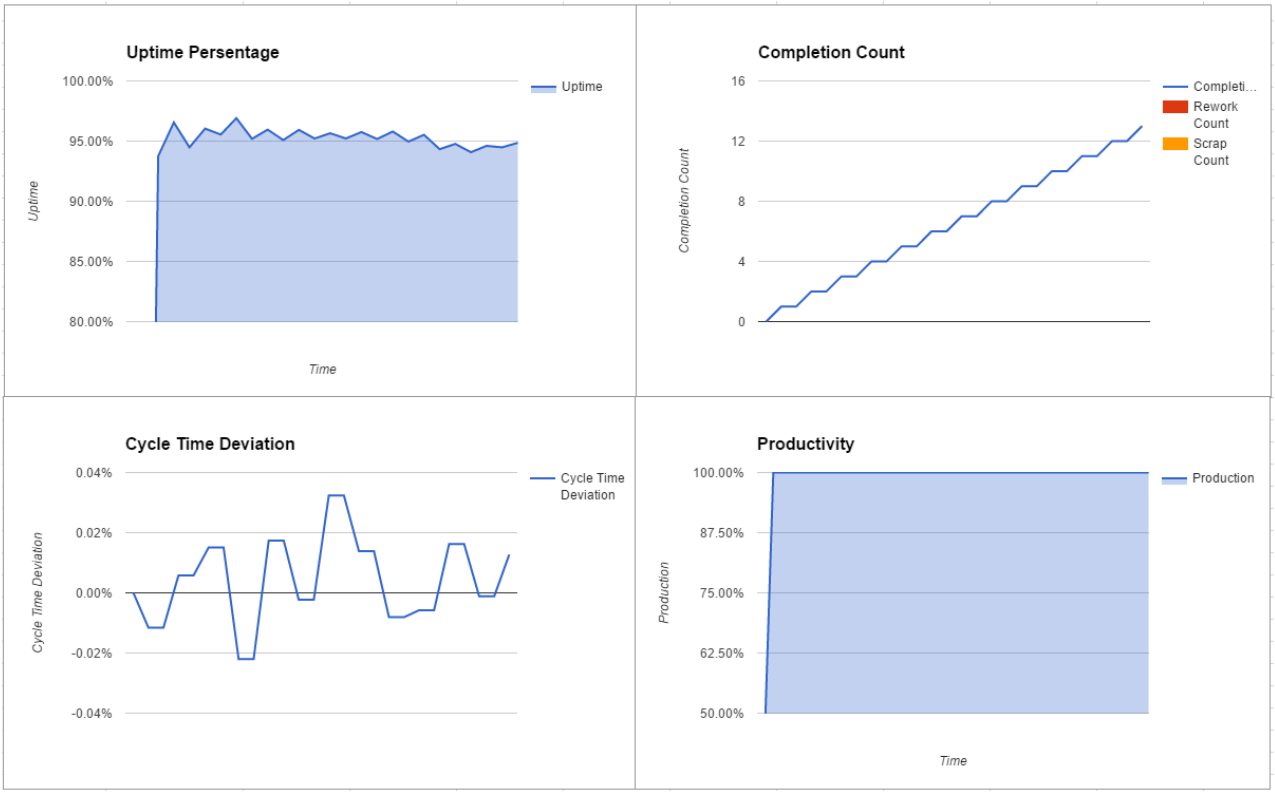
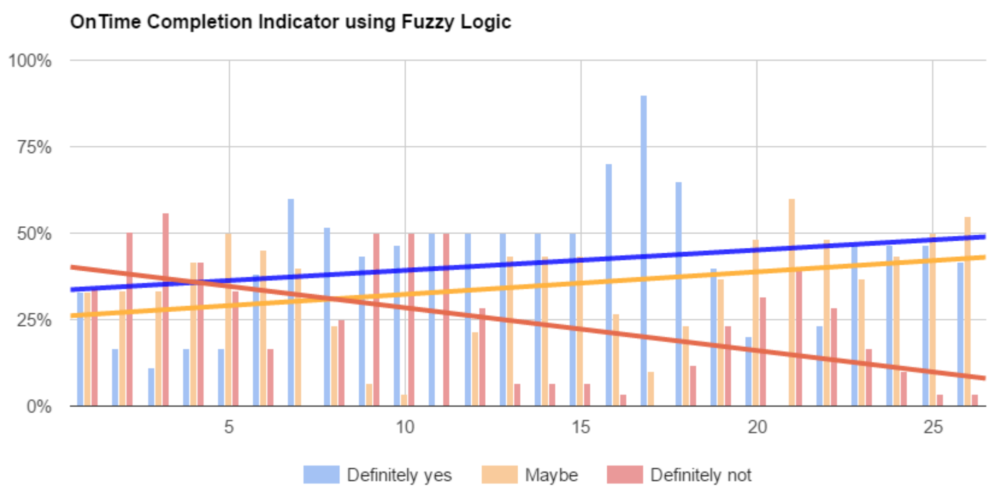


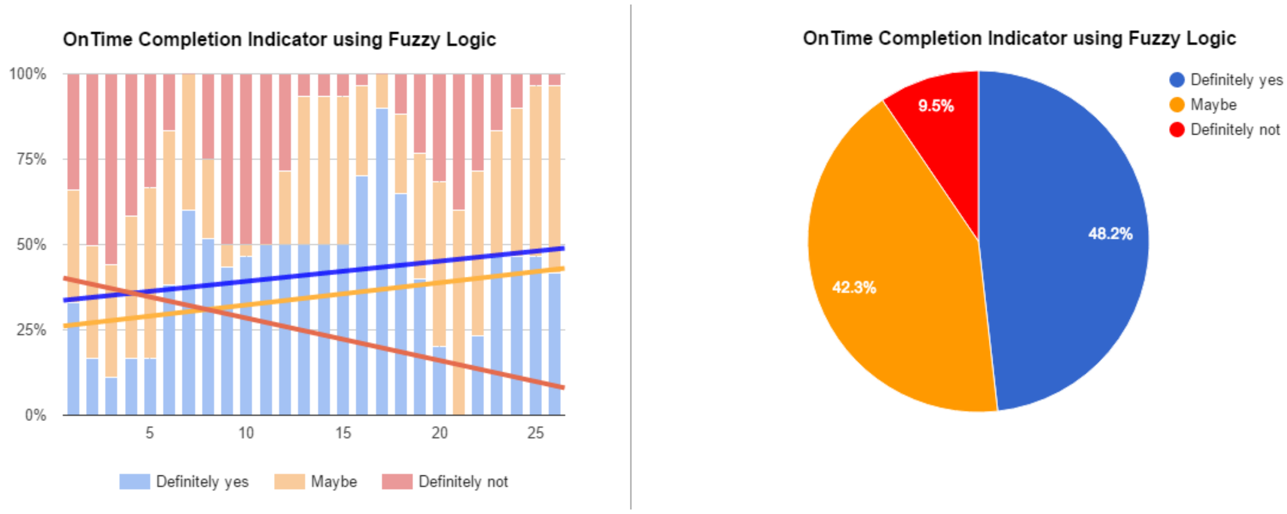
Figure 3-14: SLF Smart Dashboard for the first case

The dashboard for Workstation 3 in Figure 3-14 displays the exact same data as the previous case study with the exception that the fault count was reduced to zero. The difference, therefore, is that the productivity of Workstation 3 is now 100% for the complete monitored production cycle. The information displayed in Table 3-6 shows the twenty-six data points collected for the thirteen products of Workstation 3. However, to determine the possibility of job completion over time, a moving average is calculated from the data points and is represented with the stacked bar chart of Figure 3-16. This moving average of five past percentages created the trend line necessary to predict the future and linguistic variable output. The use of the stacked bar chart was used to simplify the representation of the moving average, but in Figure 3-15 a column chart is used to represent the same data to convey more information regarding the trend prediction.

Figure 3-15: SLF's smart dashboard showing the first case's informative column chart



The figure above displays each of the condition percentages next to each other for each data set and illustrates how the trend lines of the data is produced. The actual figure used, the stacked bar chart, shifts the focus of the viewer more to the 'definitely yes' condition and was chosen to represent the data on the dashboard to produce the following extension of the original dashboard that can be seen in Figure 3-16.



(a) *(b)*

Figure 3-16: SLF's smart dashboard showing the first case's (a) trend lines of cycle times and the (b) possibility of on time completion pie chart

The chart on the left displays the cycle time deviations' fuzzy logic percentage representation of the linguistic variables together with their trend lines. The pie chart on the right of Figure 3-16 represents the current prediction of on-time completion at the last timestamp. Both charts are dynamically updated as soon as new data sets are posted to the online database. Therefore, the trend line is not going to continue at its current projected angle, but will change dynamically to represent the new trend outcome as soon as the data logger populates new data sets to the databases. The information gathered from the above dashboard extension is as follows:

1. The trend line for definitely completing on time is positive. There is a 48.2% chance that the project will be completed in time.
2. The trend line for maybe completing on time is also positive. There is a 42.3% chance that the project may be done in time.
3. The trend line for definitely not completing on time is negative. There is a 9.5% chance that the project will not be done in time at the last timestamp.

With this information, the probability of completing the project is 48% ‘definitely yes’ and 42% ‘maybe’, making the project’s timely completion a high possibility. Plotting this on the fuzzy logic graph can be seen in Figure 3-17. The reason for the 10% deviation is the moving average calculation of five previous data points.

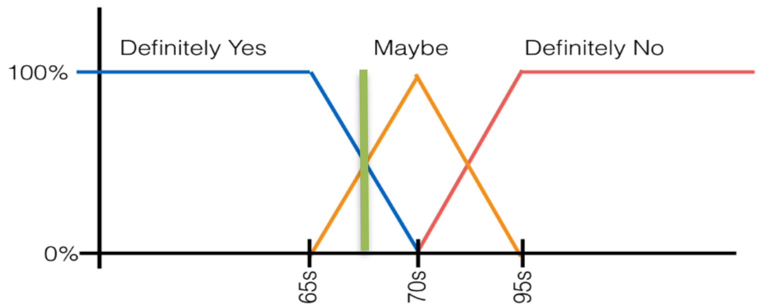


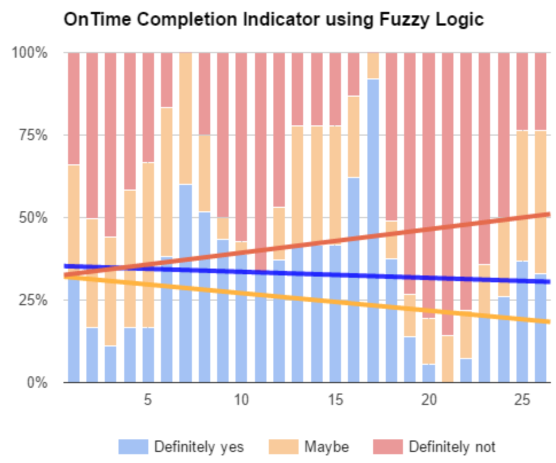
Figure 3-17: SLF perfect run fuzzy logic indicator

Now, the comparative second case introduced the same concept as the first. In this case though, the second rule, this rule regarding the fault count in production, is also introduced. In the production run of Workstation 3, there are eleven products completed with two products removed the fault count equal two. The dashboard therefore represents the same one as previously displayed in Figure 3-10 of the previous section (see section 3.4.2), however the data to create the fuzzy logic second case dashboard is captured in Table 3-7.

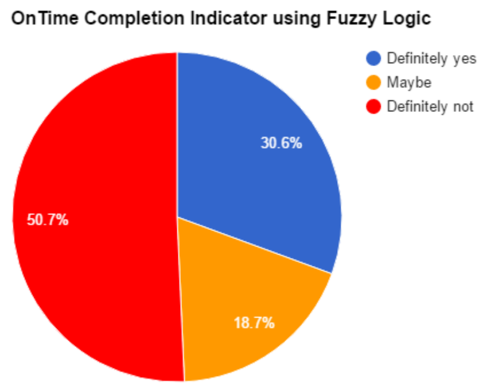
Table 3-7: SLF's smart dashboard showing second case tabled data

Product	Condition	Time	Cycle Time	Fuzzy Rule 1: Cycle Time Deviation	Total Faults	Fuzzy Rule 2: Fault Count Factor	Definitely yes	Maybe	Definitely not
1st	Start Time	2:01:54 PM	0:00:00	0:00:00	0	1,00	33,00%	33,00%	34,00%
1st	Finish Time	2:03:14 PM	0:01:20	0:00:10	0	1,00	35,03%	31,35%	33,72%
2nd	Start Time	2:03:19 PM	0:00:05	0:00:10	0	1,00	34,85%	30,82%	34,43%
2nd	Finish Time	2:04:24 PM	0:01:05	-0:00:05	0	1,00	34,67%	30,29%	35,14%
3rd	Start Time	2:04:27 PM	0:00:03	-0:00:05	0	1,00	34,48%	29,77%	35,85%
3rd	Finish Time	2:05:24 PM	0:00:57	-0:00:13	0	1,00	34,30%	29,24%	36,56%
4th	Start Time	2:05:25 PM	0:00:01	-0:00:13	0	1,00	34,12%	28,71%	37,27%
4th	Finish Time	2:06:54 PM	0:01:29	0:00:19	0	1,00	33,93%	28,19%	37,98%
5th	Start Time	2:06:59 PM	0:00:05	0:00:19	0	1,00	33,75%	27,66%	38,69%
5th	Finish Time	2:07:54 PM	0:00:55	-0:00:15	1	0,50	33,57%	27,13%	39,40%
6th	Start Time	2:07:57 PM	0:00:03	-0:00:15	1	0,50	33,38%	26,61%	40,11%
6th	Finish Time	2:09:09 PM	0:01:12	0:00:02	1	0,50	33,20%	26,08%	40,82%
7th	Start Time	2:09:12 PM	0:00:03	0:00:02	1	0,50	33,02%	25,55%	41,53%
7th	Finish Time	2:09:54 PM	0:00:42	-0:00:28	1	0,50	32,83%	25,02%	42,24%
8th	Start Time	2:09:56 PM	0:00:02	-0:00:28	1	0,50	32,65%	24,50%	42,95%
8th	Finish Time	2:10:54 PM	0:00:58	-0:00:12	2	0,33	32,47%	23,97%	43,66%
9th	Start Time	2:10:57 PM	0:00:03	-0:00:12	2	0,33	32,28%	23,44%	44,37%
9th	Finish Time	2:12:14 PM	0:01:17	0:00:07	2	0,33	32,10%	22,92%	45,08%
10th	Start Time	2:12:19 PM	0:00:05	0:00:07	2	0,33	31,92%	22,39%	45,79%
10th	Finish Time	2:13:34 PM	0:01:15	0:00:05	2	0,33	31,73%	21,86%	46,50%
11th	Start Time	2:13:42 PM	0:00:08	0:00:05	2	0,33	31,55%	21,34%	47,21%
11th	Finish Time	2:14:38 PM	0:00:56	-0:00:14	2	0,33	31,37%	20,81%	47,92%
12th	Start Time	2:14:43 PM	0:00:05	-0:00:14	2	0,33	31,18%	20,28%	48,63%
12th	Finish Time	2:15:54 PM	0:01:11	0:00:01	2	0,33	31,00%	19,76%	49,34%
13th	Start Time	2:15:55 PM	0:00:01	0:00:01	2	0,33	30,82%	19,23%	50,06%
13th	Finish Time	2:16:54 PM	0:00:59	-0:00:11	2	0,33	30,63%	18,70%	50,77%

The productivity decreases when a product is taken out of the production process and affects the production negatively, making it questionable if it can be completed in time. The extended fuzzy logic data is displayed in Table 3-7 and the extract of the additional dashboard is shown below in Figure 3-18.



(a)



(b)

Figure 3-18: SLF's smart dashboard showing second case's (a) trend lines of cycle times and the (b) possibility of on time completion pie chart

The information from the second case's outcome is the following:

1. The trend line for 'definitely yes' completing on time is negative. There is a 30.6% chance that the project will be done in time.
2. The trend line for 'maybe' completing on time is also negative. There is an 18.7% chance that the project may be done in time.
3. The trend line for 'definitely not' completing on time is positive. There is a 50.7% chance that the project will not be done in time.

With this information the probability of completing the project is 51% 'definitely no', making the project completing in time a low probability. Plotting this on the fuzzy logic graph can be seen in Figure 3-19.

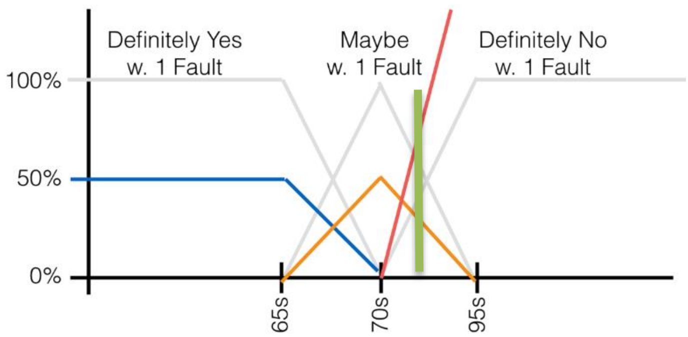


Figure 3-19: SLF run with fault count fuzzy logic indicator

For the validation of this case study, a questionnaire was sent out to the research group to perform the same longitudinal research method validation (see Appendix C for a copy of the questionnaire). The questionnaire compares pre- and post-opinions regarding smart production system implementation within SLF. The objectives of this questionnaire was to:

1. Determine the opinion of the participants regarding artificial intelligence and the successful implementation thereof within SLF.
2. To determine how well the participants understood the information that was presented to them, before and after using VMS.

The first objective is achieved by asking the following question to the participants in the questionnaire: Do you think a prediction of Workstation 3's ability to finish a project on time using the Fuzzy Logic algorithm is possible? The results are captured in Figure 3-20.

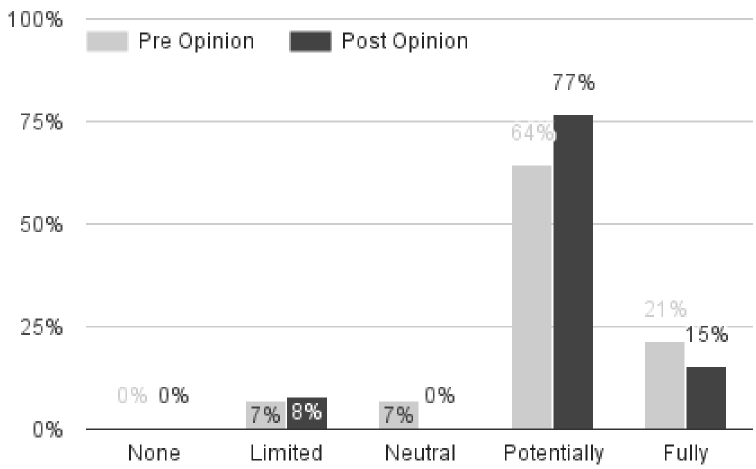


Figure 3-20: SLF and AI implementation question results

In workstation 3's example of intelligence, the use of fuzzy logic method actually had the effect of producing a high acceptance of potential implementation of smart production systems. The expected results were to see a low chance of implementing intelligent principles and then after the case study is explored, the general opinion of the participants would increase. Another expected result could have been that the participants could have had high expectations of the intelligence adding factors and then decided that adding fuzzy logic to predict the production outcome wasn't what they were expected and, therefore, do not meet expectations. Nevertheless, the results show that the general accepted possibility is highly implementable goal of smart production systems by the participants before and after the case study was captured.

The second objective was to test the level of comprehension that is conveyed with the use of VMS and smart production systems. In the questionnaire, the production dashboard was first presented with the uptime percentage, the cycle time deviation, the fault count and the productivity percentage of Figure 3-14. The participants are then introduced to fuzzy logic and describe how the rules was set up to produce the VMS dashboard extension. As explained in the case study, the rules include the cycle time deviation as the first rule and the second relates to the fault count of the products. The results of the participants' comprehension level of the data can be seen below in Figure 3-21 and Figure 3-22, which compare the case study comprehension for both fuzzy logic rules respectively. For reference, Figure 3-21 is the perfect production run where the fault count is ignored and Figure 3-22 is the same result with the addition of the fault count fuzzy logic rule. The reason for this setup is to make the two cases comparable under the longitudinal research design.

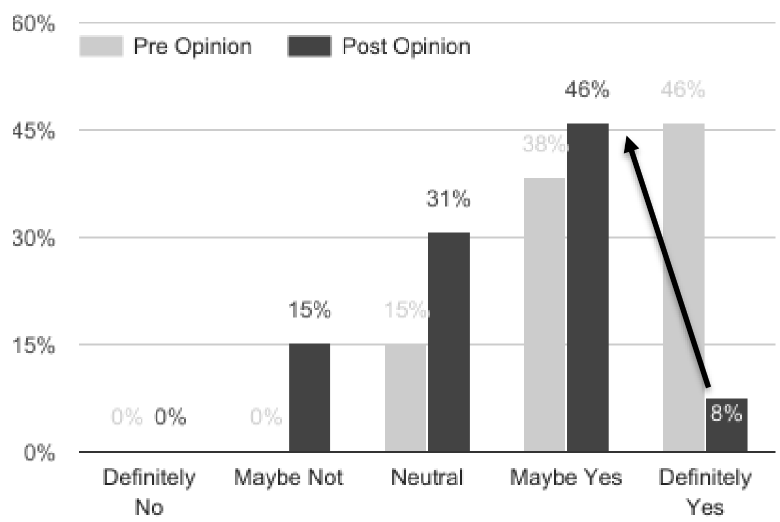


Figure 3-21: SLF prediction results of the smart dashboard's perfect run case

From Figure 3-21, which presents the results of the first case, it can be deduced that the participants could estimate that the production was on track, but they did not know to what extent. Therefore, 46% overestimated that the production completion would be definitely completed on time. However, after being introduced to the fuzzy logic dashboard extension, the participants could then make more accurate predictions with 38% reducing their expectation of the production outcome, agreeing that there is a fifty-fifty percent chance of the production being on time. With this test, the second objective is confirmed for the first case that investigates the level of comprehension from the fuzzy logic dashboard by the participants.

The second case consists of a more accurate overlay of the before and after comprehension level of the participants. Deductions can be made from Figure 3-22 that the participants expected the production process not to be on track, which is confirmed by the fuzzy logic dashboard extension.

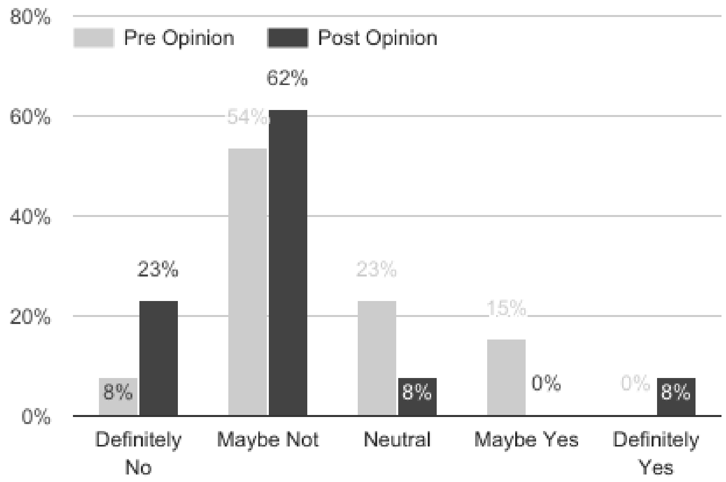


Figure 3-22: SLF prediction results of the smart dashboard's fault count case.

More than half of the participants choose the correct linguistic variable for the production process for both the before, just displaying the original KPI dashboard of Figure 3-10, and after the fuzzy logic dashboard extension of Figure 3-18 of the questionnaire. The second objective, that tested the comprehension level of the participant, of the second case is, thus, validated successfully in that the participants could successfully predict the production condition from the dashboard and the fuzzy logic dashboard extension.

The goal of this section is to produce a smart production system that improves the amount of information that can be gathered in production and to which smart production principles are added in the form of a fuzzy logic algorithm. To conclude this section, fuzzy logic is introduced to Workstation 3's dashboard and production data to serve as smart production systems with a dashboard indicating completion rate trends. The implementation of this element showed some intelligence can be incorporated within the production line and that predicting the outcome of the production cycle in linguistic variables was a possibility. The two comparative cases used for the questionnaire were set up to produce a first case with no faults and a second where fault count were introduced back into the original workstation 3 data set. After the validation testing, with the use of a questionnaire (see Appendices B and C), the results are validated and the objectives of this section achieved.

3.4.4 *Automation Pyramid*

During recent years, industrial automation witnessed the trends where M2M communication, machine learning and IoT were introduced within the manufacturing industry and therefore a lot of data is being produced by the shop floor that can be collected [21], [22], [68]. As a result, the automation pyramid architecture was developed to comply with a managerial structure of information flow and operational levels. The pyramid architecture of the automation pyramid demonstrates how the levels of management can interact with each other through information distributing and communication channels [21], [22], [65]. Figure 3-23 provides a breakdown of the automation pyramid with its levels of management consisting of ERP level, MES level and the device or shop floor level.

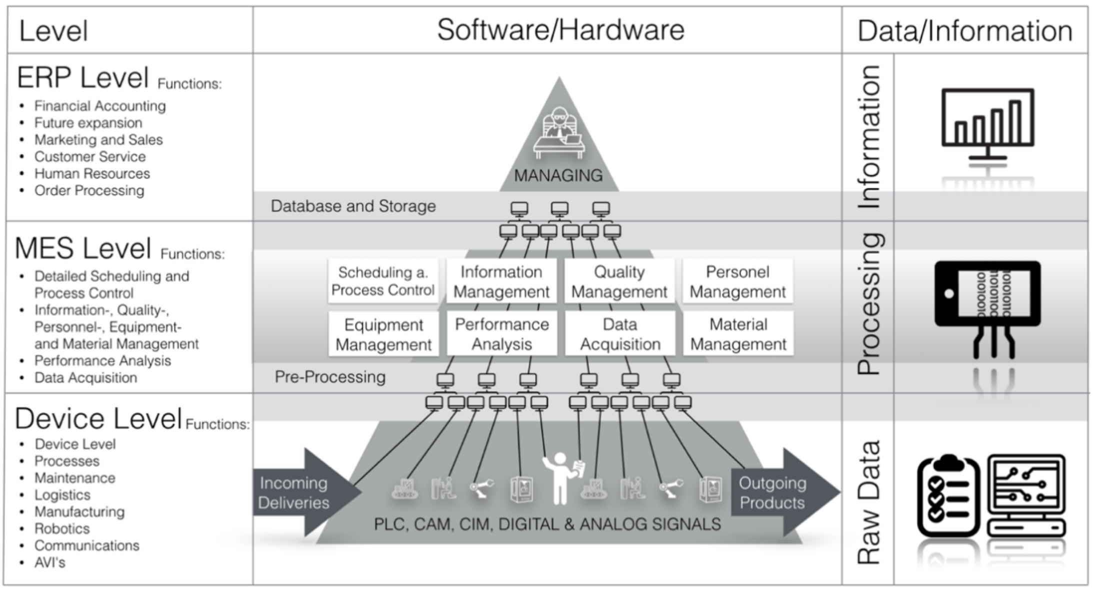


Figure 3-23: Automation Pyramid compiled from Zuehlke (2010) [22]

The automation pyramid and an example of how information collected and flow upwards can be seen in Figure 3-23. This PRITA can be used within manufacturing industries to process data and deliver valuable information that promotes improved decision-making throughout the organisation [7], [22], [65], [66]. In this section, the current automation pyramid architecture is discussed in order to relate it to the IT architecture requirements needed to support VMS. The current three level automation pyramid architecture is chosen owing to its ability to conform to both the managerial structure of industry and user specific information handling. Such a feature provides the structure to integrate IoT and related technologies into the production environment whilst providing separate levels for user interaction.

The Department of Industrial Engineering at Stellenbosch University has many services that it offers, through projects such as the Institute for Advanced Tooling (IAT) and the Rapid Product Development laboratory (RPD), to university students, industry and other institutions. These services include the use of very advanced software and manufacturing equipment. Stellenbosch Technology Centre's Laboratory for Advanced Manufacturing (STC-LAM) was formed when the decision was made to incorporate internal and external projects so as to make the laboratory a centre that could provide the opportunity to create research opportunities around manufacturing and provide multiple projects where data could be collected. The STC-LAM is an institution that now provides excellent quality products in small quantities with high precision. The focus of this section will be to introduce new IoT technology in the STC-LAM environment. This is achieved by expanding the ERP and MES data handling and processing capabilities with the introduction of IoT and related technologies.

In a discussion with RPD lab and STC-LAM research group on the scope of this topic, the automation pyramid is explained and the general opinions sought in order to generate important points of information context. The automation pyramid is used as framework and the flow of data explained to the research group. The end goal is to investigate KPIs and production related information that could then be processed and captured within a dashboard or a similar visual management tool. The research group agreed that the following are important aspects: Better planning, scheduling and managing of resources, filtering down this automation pyramid eventually becoming a lean system from all aspects of the production activities. Subsequently, a hypothesis is introduced to determine their opinion: Can a highly automated and sensing factory floor assist a visual management tool within a manufacturing environment improve production related decision-making? Based on their response and their knowledge of IoT, the following three questions were asked:

1. How have you been introduced to IoT and related technology?
2. How can IoT be introduced to the STC-LAM manufacturing environment?
3. How are you, as a potential academic, employee or client, going to benefit if it was possible to access some of the information online and what important KPIs could be incorporated?

When asked the question that correlated with the hypothesis, ninety-three percent of the research participants agreed that if more sensors and automation technology within a factory environment are introduced, the result would increase the manufacturing or shop floor resource management efficiently. Participants also observed that the addition of a VMS could have lasting implication on an organisation, a claim that is supported by the vision of Lee et al (2014) [13]. In the first question of the interview, the interviewee had the chance to indicate if he/she was already introduced to some of the IoT and related technologies. Just over fifty percent of the interview group indicated that they had interacted with these concepts first hand, in previous work experience or academia. However, almost a quarter of the sample had not heard of these concepts prior of the discussion. The feedback forms part of the way information should be presented: extensive and easily accessible (see Appendix D for a list of other important feedback factors).

VMS for individual user or managerial levels that is displayed on this dashboard can incorporate all the important KPI's of the STC-LAM production processes. The dashboard may also be accessible on an online platform for academic and client-based monitoring for convenience and improved involvement. The methodology to develop a VMS firmly consists of collecting data, processing the data and then making decisions based on the information. Thus, a digital data input point had to be developed to accomplish these tasks on different managerial levels. Before this is accomplished, the value stream is investigated and three possibilities for deployment opportunities are produced as displayed in Figure 3-24.

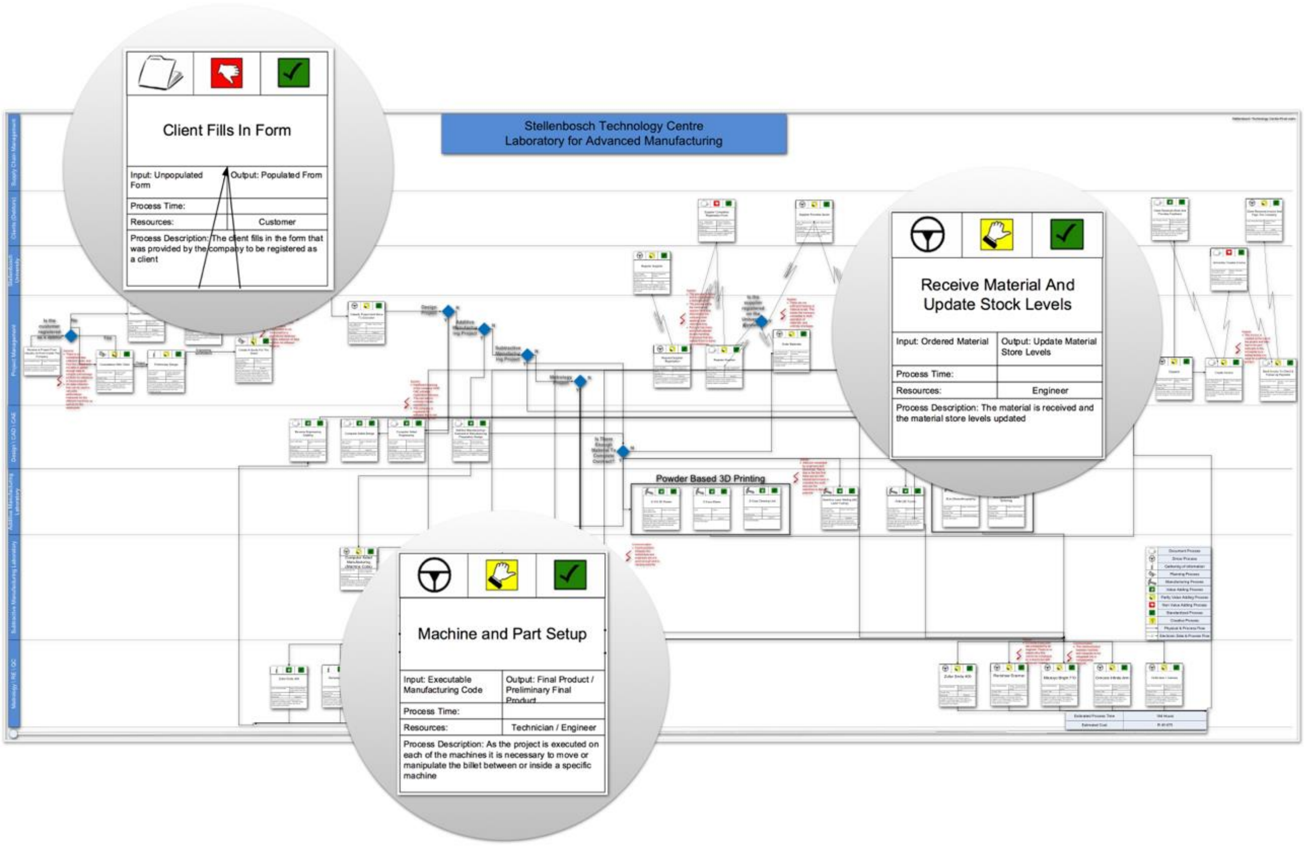


Figure 3-24: STC-LAM's value stream map compiled from Saxer (2015) [38]

The three points of interest that are investigated further within the STC-LAM's value stream are as follows:

1. Client's fill in form: The first point of contact from the client, which also eases the project creation and defines the order capturing process. Here, a mobile platform could be implemented to capture the project details and provide a platform to communicate changes or updates of the design with the client or to show progress of the project's completion.

2. Receive Materials and Update Stock Levels: Mobile technology can be implemented at the warehouse to monitor inventory and update stock levels by providing a platform to input incoming and outgoing materials and/or tools.

3. Machine and Part Setup: A crucial stage of the value process chain is to check if the required materials and tools are in stock to fulfil the client's order. Here, the person in charge (operation manager) of the project can access the information generated by the previous mentioned points of interest to determine if the project can be executed. A job card could also be sent to the

project leader to inform him/her that the materials and tools needed to start the job have been loaded into inventory.

All three points have correlation factors in common. They consist of three levels of specific user interfaces that contains details of the materials and tools necessary to complete the project. Therefore, by just incorporating user specific information possibilities in these three areas will possibly increase transparency and control in the whole production process and will be explored in the next section. The STC-LAM is an example of SME within the manufacturing industry of South Africa. Therefore, to jumpstart the process, the introduction of mobile technologies is investigated in its context by expanding the ERP and MES, and data sourcing and processing capabilities of the shop floor. The information generated can then be accessible on a mobile platform for academia, clients and the entire STC-LAM workforce. Thus, investigating possible specific user interface contact points within the value stream and then adding mobile technology and cloud computing to support the managerial levels architecture will be investigated in the next section.

3.4.5 *Mobile Technologies*

Smart phones and tablets are increasing prominent in our lifestyles. The obvious next step is to start introducing these devices into the workplace and integrate them seamlessly together for concurrent design and development. This case study investigates just this: investigating the mobile technology and its role in the management structure in a case study that determines the possibility of building on the current automation pyramid IT architecture framework. This is accomplished by implementing mobile technology on user specific information and determining the impact and visual management techniques that could be introduced for it to be successful. This could be a company specific designed group of applications for different levels of management or one application with different user levels of interactions that fit perfectly into the automation pyramid framework. This is necessary for companies to start embracing mobile technology in manufacturing to support an active environment provided by mobile technology that can increase productivity and in so doing, collaboration and innovation naturally improvement [25], [105]. Thus, the use of mobile technology for the purpose of satisfying the need for accessible information, in combination with IoT and related technology, within the manufacturing industry is investigated. STC-LAM and the Institute for Advanced Tooling (IAT) provides the setting for this case and is considered to be mobile technology and cloud processing ready and the implementation process is illustrated in Figure 3-25.

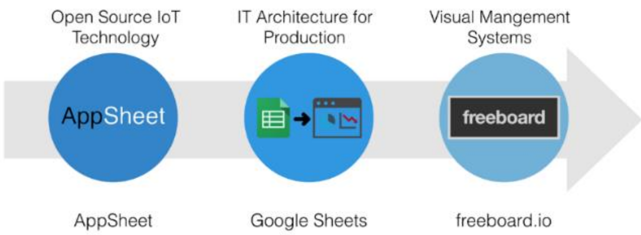


Figure 3-25: Proposed STC-LAM and IAT's mobile technology and cloud computing implementation process

An online mobile application generating website called AppSheet was incorporated to develop this case study. It is an online freeware mobile application generator that can be used on smart phones, tablets and produce a desktop version. However, to publish the mobile application on Apple App Store or Google Play Store requires a monthly fee [106]. The method of creating a mobile application starts by opening a new Google Form and set up the application as a questionnaire that can gather the required information through a question and input method [107]. Thereafter, with the activation of the AppSheet add-on in Google Form, a Google Sheet that captures the responses are generated automatically. Then, by launching the AppSheet newly created mobile application, the layout and some of the input types of the application can be changed to address the input requirements [107].

Three mobile applications were developed to investigate the three application opportunities that have been determined in the previous section and can be seen in Figure 3-24. Description of the three mobile application are: Figure 3-26 that investigates the IAT Client Capturing Form, Figure 3-28 that investigates resource and inventory management, and Figure 3-29 that illustrates a dashboard for the shop floor and correlates with the three points of interest of the STC-LAM value stream of Figure 3-24.

The first application is an exact replica of the client capturing form of the IAT (see Appendix E for the form). The goal was to develop the mobile application and investigate the difference in the current process to that of the mobile application equivalent. The current client capturing form and project completion process consists of three steps:

1. The form is send to the new to provide information regarding the new project. A specific description of the product, a CAD model or a sample of the product then signs the form and send back to IAT;

2. A operation manager is then dedicated to the project by IAT and goes through the process of updating CAD models, receiving the material to manufacturing the product/s in the STC-LAM and deliver the finished product/s back to the client and finally sign off on completing the project on the same client capturing form;

3. Lastly, the completed project is signed off as successful by a technologist of IAT if the client is pleased with the project and then add all the information of the project to a project list database.

In an expert interview with an IAT technologist, the process of the client capturing form was explained in which the interviewee stressed the importance of the three signatures for administration purposes. The client capturing form mobile application, that can be seen in Figure 3-28, was then presented for comparison. The first mobile application is a project generating application following the procedure set out by the IAT project generation protocol (see Appendix E for the client capturing form of IAT and Appendix F for larger version of the mobile application and the creation process thereof).

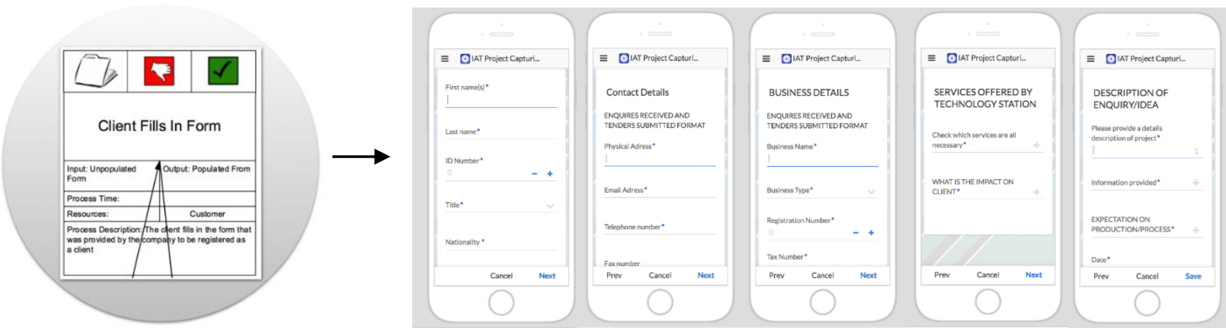
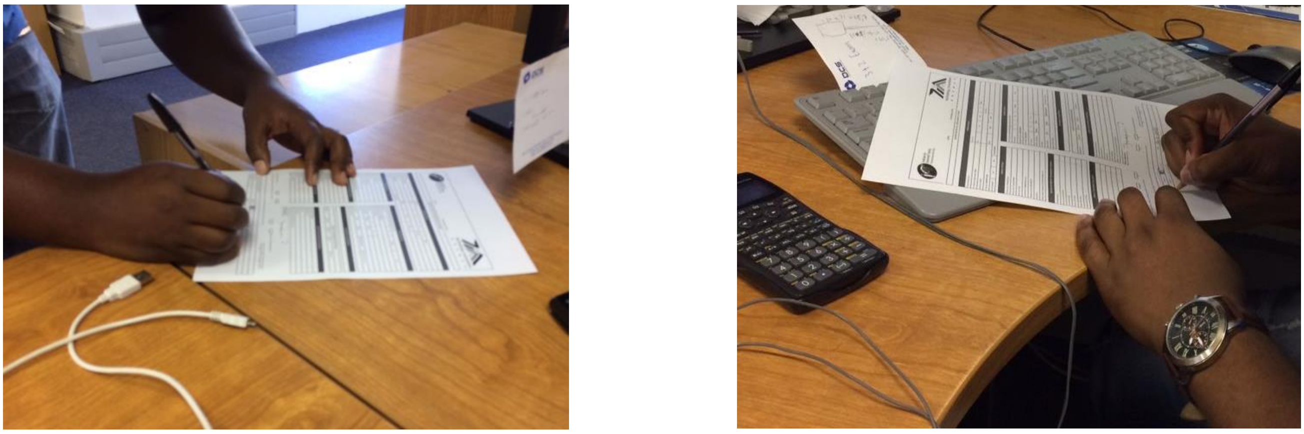


Figure 3-26: Mobile Application based on the IAT Client Capturing Form

The expert interview with the technologist of IAT produced a negative response to the mobile application and therefore rejected the full implementation of it. It was agreed upon that the client capturing form mobile application was an exact replica of the actual form, but due to the current process being superior in the method of capturing all the necessary party's signatures on one page for administration reasons, it failed to improve on the process. Other comments produced by the expert interview included that the method of not having a pdf form format similar to the client capturing form and capturing the data in a table format produced by the mobile application complicated the information handling process. In Figure 3-27 the manual process that consists of printing the form to be signed by the operation manager and technologist can be seen.



(a) (b)

Figure 3-27: IAT client capturing form showing (a) the operation manager and (b) the technologist signing off on a completed project.

The interview concluded with suggestions added to improve on future implementation of mobile applications in the project capturing process: an improvement to the current method could be to create an online interactive form that can be shared to the client with the use of a url link. This online form will improve collaboration between the client and the IAT personal and will not require the form being emailed back and forth. The form can therefore be shared with the client through a login portal and when both the client and technologist are pleased with the client capturing form, an operational manager gets dedicated to the project. This new suggested method will save time and improve on the current process according to the IAT expert interviewee.

The second mobile application was dedicated to investigating resource and inventory management and can be seen in Figure 3-28. The goal is to investigate the use of a mobile technology and cloud computing to address MES level of operations and produce a third mobile application that can relate the information on an online dashboard. The mobile application consisted of a generic inventory order, receive and remove of tools out of inventory (see Appendix G for larger version of the mobile application and the creation process thereof).

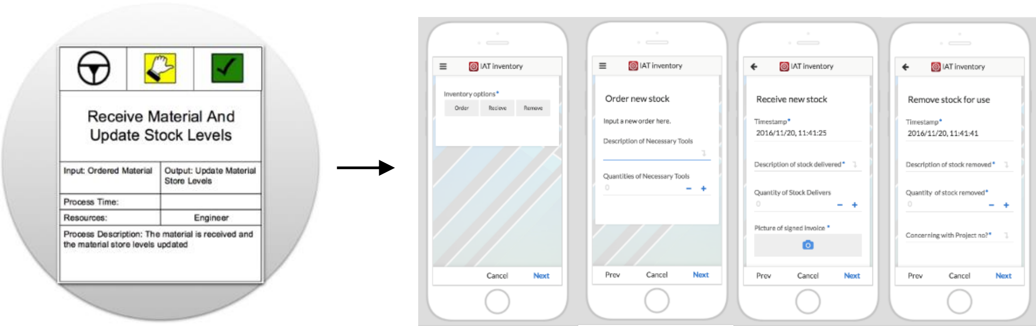


Figure 3-28: Mobile application investigating inventory management

In this application the option is provided to choose between three inventory handling conditions: ordering new condition that takes the user to a page that asks for details of what tools are needed and the quantity; receiving orders that takes the user to a page that shows a timestamp and asks for details together with a picture of the delivery note; the third option is for removing items from inventory and therefore asks the user to produce details on the items and the project for which it will be used. The application was explained to the IAT technologist in the same expert interview and the use thereof in collaboration with the dashboard of Figure 3-29 was demonstrated.

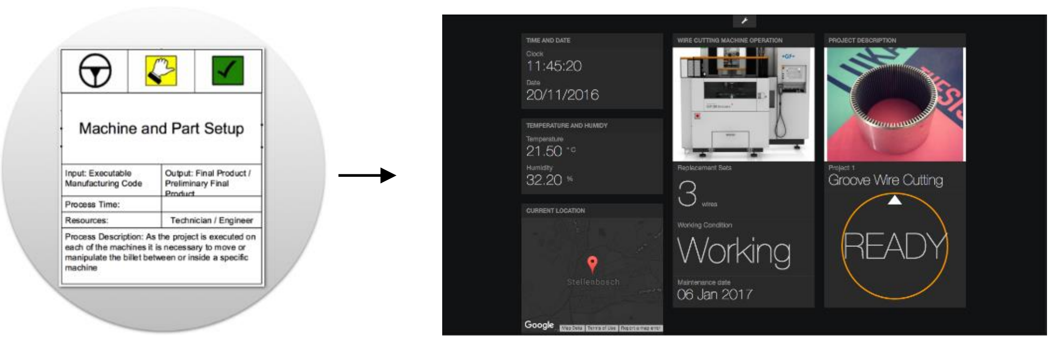


Figure 3-29: Mobile dashboard investigating shop floor inventory and project awareness

After the demonstration of the mobile application and the dashboard pair, the expert interviewee agreed that this implementation is more applicable and that there is a need for such a system. The dashboard can display the project information regarding the machinery and tools required to complete a project and can indicate if the project is ready for execution. The interviewee liked the layout, the way the dashboard presented information and the use of a picture of the project. Freeboard.io proved to be a powerful tool and can handle multiple input methods and visualization techniques that are easily programmed to achieve colourful and eye-catching displays. It is also an open source software design with free basic services that integrated with Google Sheets and AppSheet for this case study [104].

In this study, the mobile technology element of VMS is investigated to show implementation capabilities the STC-LAM and IAT context. The tool used Appsheet to gather data, Google Sheets as the database, and Freeboard.io to display the mobile application information, all of which are open-source online applications [104], [107]. These mobile applications and cloud processing capabilities are used in a case study to demonstrate proof of concept that forms part of the VMS model with the goal of investigating communication contact points within an organisation using mobile applications.

In the South African context, these type of technology advancements should be implemented to bridge the problem of unsystematic approaches within the project execution. The use of mobile technology or online sign-in solutions will increase the traceability of documents and the process for responsibility monitoring purposes. Challenges within the methods of capturing information and updating the process to a more digital friendly version needs addressing, but this case study serves as a proof of concept for the implementation thereof.

3.5 Conclusion

The goal of this chapter was to investigate the implementation process of VMS, starting with a descriptive model of its capabilities to produce elements providing vital functionalities. The next preceding sections describe the process of investigating and determining the necessary PRITA systems that can support VMS elements' functionalities. The objective was to extend the current VMS model with PRITAs that could be implemented in the manufacturing environment in order to support the sourcing and processing of data necessary to produce the information to the VMS. The process consisted of VMS requirements and current PRITA system correlation testing to produce the final model. An example of information sourcing and processing in the manufacturing industry setting is discussed, followed by an elaboration of the operational system requirements that must be addressed in order to create a PRITA that could be successfully implemented.

This chapter then provided a detailed discussion of the PRITA and VMS model developing process and implement four prototypical implementation examples to investigate and validate the research. Prototypical PRITA and VMS model implementations in four case studies were completed and a summary of the findings is discussed in the next chapter.

Chapter 4. RESULTS AND DISCUSSION

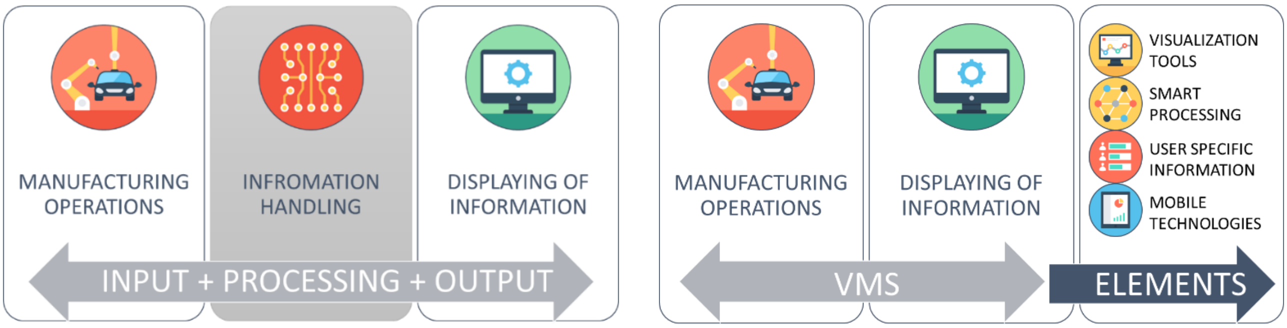
4.1 Overview

This chapter details the results of the methodology and discusses it in retrospect to the research objectives. The objectives were to:

1. To investigate and define VMS with the aim of developing a model for effective information communication.
2. To define elements of PRITA systems that meet the prerequisites for VMS.
3. To develop case studies that investigate and validate the implementation capabilities of the developed PRITA and VMS model.
4. To determine the influential or beneficial factors of VMS.

4.2 Objective 1: VMS Model

This section discusses the exploration process undertaken to meet the first objective. The task was accomplished by studying the information communicating possibilities to create a VMS model that supports the sourcing and displaying of production-related information that is vital for users. The information handling aspect, therefore, needs to source, cluster and process data from manufacturing environment and translate them into production information or KPIs for management. Thus, VMS can improve the users' comprehension level of the production process activities. The necessity for investigating VMS and its elements is depicted in Figure 4-1. The model includes elements that satisfy the functionality needs of a VMS. These elements consist of four different output devices and serve as the basis for exploration of the next objective.



(a) *(b)*

Figure 4-1: Objective 1 – (a) Need for VMS and (b) elements of VMS Model

Determining the four elements consisted of a research approach of incremental design requirements. The first element provides the visualisation tools for displaying information in the manufacturing environment for users to quickly and effortlessly understand presented information. The second is a predictive element called smart processing. It provides the model with the capability of processing the data using fuzzy logic techniques in order to determine trends and provide valuable feedback trend analysis to the users. The third element provides the ability of managerial control with secure information communication to specific users. The fourth element provides the VMS model with the mobility of mobile technology and cloud computing that allows the model to be dynamic and versatile over platforms. Here, VMS is defined as a holonic information sourcing, processing and displaying system with the goal of heuristic process understanding.

4.3 Objective 2: PRITA Model

This section details the investigation process in order to find the specific PRITA systems that met the prerequisites of VMS elements and provide the necessary IT and information handling support functions. The process involved researching and listing the appropriate PRITA systems and then clustering their functionalities according to their information sourcing and handling capabilities. These PRITA clusters and their role within the elements, are then chosen through a correlation testing of functions and added to the VMS model. The model consisting of an integrated PRITA and VMS model can be seen in Figure 4-2.

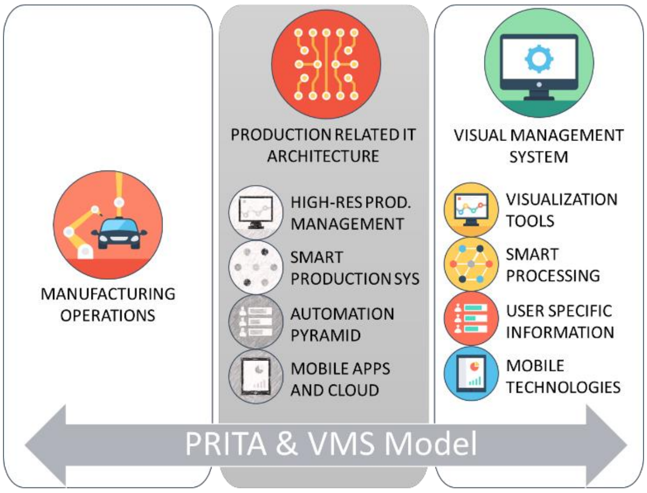


Figure 4-2: Objective 2 – PRITA and VMS model

The four PRITAs link directly to the VMS elements in Figure 4-2. These PRITAs have the following roles: HRPM provided the visualisation element of data sourced and processed from the product value stream and supported IoT and other related technology. The second PRITA, smart production system, incorporates both SF and CPPS into the smart processing element and provides the support function of intelligent data processing and production-related knowledge integration. The third PRITA, VMS element, requires user specific information and, therefore, the automation pyramid architecture is dedicated to this element. The automation pyramid has a three level breakdown architecture that consists of ERP, MES and shop floor levels, and their information and communication requirements. The last VMS element is supported with mobile and cloud computing technologies. These PRITAs provide the flexibility of information sourcing and accessibility for the VMS model validation. Overall, the dedicated PRITA systems should enable all the necessary functionalities of the VMS model and an investigation into implementation of the model now follows with the next objective.

4.4 Objective 3: Case Study and Validation of the PRITA and VMS Model

To validate this model in practice, case studies of all the VMS elements require development, validation and documentation of results to meet the next objectives. This objective would be considered to have been met when all four of the PRITAs and VMS model elements have been incorporated into a production environment specifically to test the implementation capabilities of the model. A breakdown of the technology that was installed before the study could proceed are shown in the most left block of Figure 4-3, with the matching case study details on the far right.

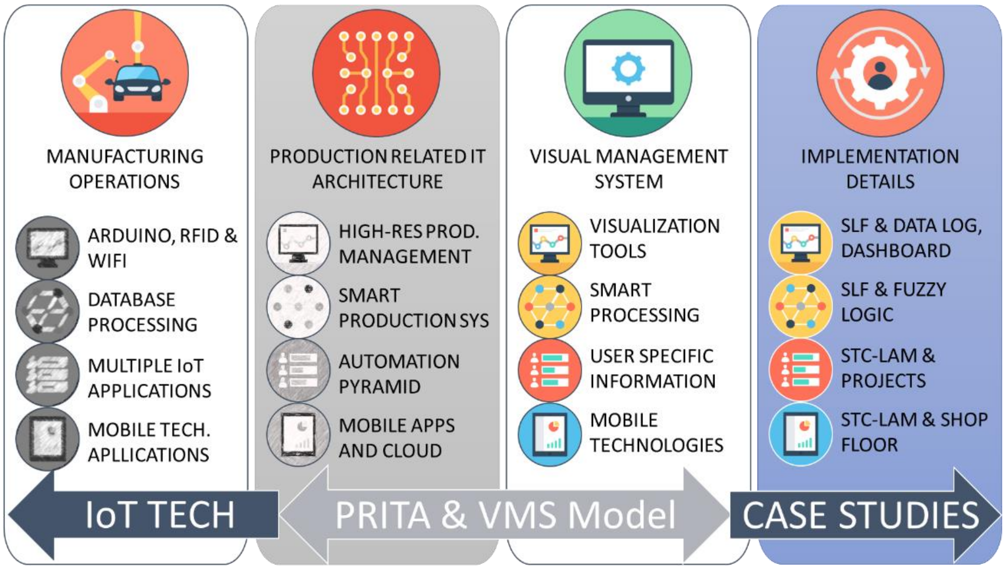


Figure 4-3: Objective 3 – IoT Technology and Case Studies

The four case studies are implemented in two different production environments. The first is the Stellenbosch Learning Factory (SLF), which is an education tool used to simulate the production environment for educational and experimental purposes. These production environments facilitate the opportunity for students to experience the manufacturing industry with the goal of understanding and integrating knowledge into contextual circumstances. Currently, the SLF focusses on teaching lean tools through the process of building small model trains. Its goal is to replicate a typical South African manufacturing SME.

The other production environment is the STC-LAM, which was to created incorporate internal and external projects to make the laboratory a centre that would provide the opportunity to research manufacturing processes. As such, the STC-LAM provides real projects where data could be collected. The STC-LAM is an institution that now provides excellent quality products in small quantities with high precision.

4.4.1 *Objective 3.1 – Visualisation Tool*

The goal of the first case was to develop a real-time online dashboard with open source technology to be used as a data capturing devices using the HRPM system as framework. This coincides with the opportunity in South Africa to communicate information more effectively to low skilled workers. A data logger was developed and was capable of souring data from the production line. This data logger consisted of an Arduino Uno microprocessor, Adafruid RFID shield and ESP8266 Wi-Fi module, and is able to post scanned RFID tags, with its timestamp, onto a Google Spreadsheet. On this spreadsheet, a dashboard was developed to display production line information consisting of timestamps that details work completion events between workstations. The dashboard is also able to show uptime percentage, cycle time deviation, scrap and rework count, and productivity in percentage.

The results of the study indicate that it is possible to develop and implement an open source dashboard within a functioning production line. 71% of the questionnaire participants (that consisted of fifteen academic and industry representatives, and lab personnel of the RPD laboratory and STC-LAM research group) agreed that VMS is becoming important within the manufacturing industry. The participants were also able to comprehend 43% more information displayed on a dashboard than the traditional method of tabulated data.

4.4.2 *Objective 3.2 – Smart Processing*

This case study built on the previous and uses the same data set. It incorporated fuzzy logic algorithms to determine the condition of operations. The goal was to establish if it was possible to predict the ability of the product line to complete on time in real-time. This was accomplished by creating two rules using the cycle time and fault count data sets and creating an algorithm that can produce a condition for how well the production is performing using the linguistic variable method of fuzzy logic. The process compares two case studies for both no-fault and two-fault count that produce a positive condition and a negative condition respectively for validation purposes.

The results of the fuzzy logic algorithm are displayed using an extension dashboard visualization tool to provide more information than just the previous case's dashboard. The first is a timeline of historic operation conditions on which a trend line has been added. The second dashboard component consisted of a pie chart showing the projected completion condition of 'definitely yes', 'maybe' and 'definitely no' in percentage. A questionnaire was sent to the same participants as the previous study and the results show that 77% of the participants agreed that VMS can successfully implement fuzzy logic algorithms to replicate smart processing capabilities. Additional result shows that after this element was implemented, the participants become more conservative with their predictions of the production line outcome and 38% of the participants adjusted their response to a lower expected condition of the production line for the 'perfect run' condition longitudinal research design study. The second study, that included the fault count of the production line, the participants were capable of comprehending the production line condition will not able to finish in time with more than 50% accuracy.

4.4.3 *Objective 3.3 – User Specific Information*

This objective required the STC-LAM and IAT as a setting for the case study. It provided a better managerial structure for the implementation of the automation pyramid architecture PRITA. The goal of this case study was to investigate the value stream of the production line and evaluate where and how information communication points can be introduced to improve on traditional communication channels. From the value stream of production, three points therein are identified: the inventory and warehouse control, the production checklist of machine and part setup, and the client fill in form, where user specific information can be communicated.

These three points of contact are important and provide managers of different levels with information vital to the effectiveness of managing manufacturing resources. Therefore, an investigation was launched to assess the modernisation of the traditional method of information flow. Whereas the traditional method only consisted of instructions being communicated downwards through the managerial levels, the modern approach sources and clusters data from the bottom upwards.

4.4.4 *Objective 3.4 – Mobile Technologies*

This case study again builds on the previous with the goal of investigating the effects of mobile technology and cloud computing when introduced to STC-LAM and IAT. This is accomplished by creating three mobile applications that collect data from different operations throughout the organisations with the goal of capturing production related information easily and quickly by different users. The goal of the case study was to develop mobile application platforms that can support the information communication points as presented in the previous section to promote modernisation of information capturing procedures. A mobile application for each was developed using the open source online mobile application called AppSheet and the dashboard developed with the help of Freeboard.io.

In an expert interview of a IAT staff member, it was determined that the mobile application that was developed to replicate the project capturing process from the client was unsuccessful due to administrative procedures not being met. However, the introduction of a mobile application and dashboard combination that investigated inventory management that could communicated inventory levels and project prerequisite information with the use of Freeboard.io's visualisation techniques were found to be beneficial.

4.5 Objective 4: Influential and Beneficial factors of VMS

4.5.1 *Effectiveness evaluation of VMS*

After the completion of the objectives and the knowledge gained from the case studies and their results, the following influential or beneficial factors of VMS became apparent:

(a) Visualisation techniques within the manufacturing industry could be implemented within organisations and are effective at conveying information to employees. The use of VMS will help with improving production line-related operation information comprehension.

(b) Smart processing of data to produce suggestions and recommendations is a feature that can be added considering the amount of information that is readily made available by PRITA incorporation. This can influence production decisions by determining trends and investigating possible solutions with problem-solving algorithms.

(c) Information can be distributed throughout the organisation on a secure and need to know basis, where data flows upwards from the shop floor and information filters downwards from ERP and MES to the shop floor according to the automation pyramid architecture.

(d) The use of mobile technology and cloud computing increases processing and accessibility to information while providing users with immediate responsive capabilities.

(e) IoT and related technology have provided a solid development platform to perform all the necessary framework support for information handling to produce visual output devices.

(f) The VMS model and its elements can be customised to meet the need of the client, customer or user.

4.5.2 *Time and Cost Analysis*

In Table 4-1 below, a breakdown of the hours and component cost that tabulates information regarding each of the individual case studies is provided.

Table 4-1: Hours and Cost Breakdown

	Case Study	Details	Hours	Labour Cost	Component Cost
1	HRPM	Arduino UNO	0.0	R0.00	R109.00
		Adafruit RFID and Cards	0.0	R0.00	R541.49
		ESP8266 WIFI Module	0.0	R0.00	R33.34
		Prototyping Shield, Rails, Wiring and Soldering	4.0	R600.00	R100.00
		Google Sheets and PushingBox Accounts	0.5	R75.00	R0.00
		Google Sheets and PushingBox Setup	2.5	R375.00	R0.00
		Arduino Coding	23.0	R3,450.00	R0.00
		Total	30.0	R4,500.00	R783.83
2	Smart Production System	Arduino Coding	2.0	R300.00	R0.00
		Fuzzy Logic Research and Coding	8.0	R1,200.00	R0.00
		Google Sheet Dashboard Setup	3.0	R450.00	R0.00
		Total	13.0	R1,950.00	R0.00
3	Automation Pyramid	Google Sheet, Freeboard.io and AppSheet Account	0.5	R75.00	R0.00
		Freeboard.io and Google Sheet Setup	1.5	R225.00	R0.00
		AppSheet Development	15.0	R2,250.00	R0.00
		AppSheet Deployment and Testing	7.0	R1,050.00	R0.00
		Total	24.0	R3,600.00	R0.00
4	Mobile Tech and Cloud	Google Sheet, Freeboard.io and AppSheet Account	0.5	R75.00	R0.00
		Freeboard.io and Google Sheet Setup	1.0	R150.00	R0.00
		AppSheet Development	13.0	R1,950.00	R0.00
		AppSheet Deployment and Testing	2.0	R300.00	R0.00
		Total	16.5	R2,475.00	R0.00
	Total		**83.5**	**R12,525.00**	**R783.83**

The time and cost breakdown in Table 4-1 shows the contribution in monetary value of each aspect of the case study implementation process. It is interesting to notice that, when a labour price per hour of R150 is introduced, the development cost consists mostly of the labour costs. For instance, the first case study's component cost totalled to less than a fifth of the total cost. A pie chart displaying the comparing component and labour costs can be seen in Figure 4-4, for both the first case study and the overall expenditures of all four case studies.

(a) *(b)*

Figure 4-4: Component and labour cost comparison of (a) Case study 1 and (b) total comparison

When comparing it to the total cost distribution, a trend emerges. As these case studies use open platforms and free online services, the majority of the expenses are contributed to the labour and the time it took to integrate and implement the VMS model. The major drawback of the self-developed system is that it is less dependable and will have security and scalability issues. Therefore, a recommendation to organisations would be to develop their own open source and organisation-specific solution using open source technology. From here, they can then provide the functionality list over to a high-end development service provider, like SAP or Qlick Sense, to support their needs [108], [109].

Chapter 5. CONCLUSION

5.1.1 *Understanding the research and objectives*

This research report discusses the methodology to investigate the manufacturing industry's information handling, communication capabilities and opportunities for introduction of new technology that can support digital visualisation and communication of information. The specific focus was to understanding how data from the production value stream can be sourced and processed to produce vital and immediate information that can be displayed in the working environment in an easy and comprehensible fashion.

The research will focus on the South African context of communicating information to the low skilled workforce with the goal of increased productivity. South Africa manufacturing industry is characterised by low skilled and low productivity of the workforce. Therefore, research into a low cost solution to increase production information comprehension was investigated with the use of open source and/or freeware visual stimuli solutions within the manufacturing environment. Case study solutions capable of supporting data sourcing and processing was developed with the implementation of production-related information technology architecture (PRITA) into the production environment. The information presentation of the processed data was then presented to a visual management system (VMS) so that the effects and benefits of the implementation thereof in the South African context could be investigated.

The longitudinal research method was incorporated to investigate the effects and benefits of the developed case studies presenting VMS and PRITA model. This research method made use of a validation process that involves capturing two sets of data on the same variable on the same sample group and mapping its change to understand casual influences over time. Therefore, the questionnaires and interviews conducted with the RPD lab and STC-LAM personnel and academics for this research consisted of the same question being asked at the start and end that investigate the change in comprehension levels of the information presented.

The methodology for this research is expressed in Figure 5-1.

Figure 5-1: Overview of Research

The methodology of this research process required development of a VMS model and investigate the extent to which its elements can influence production lines. These influences are expressed in production line KPIs and investigated using case studies to exploit niche opportunities within the South African manufacturing industry context. This niche opportunity involves presenting production information in quick and easily comprehendible fashion with the goal of increasing workforce productivity.

This study was guided by the following research question: What are the effects and benefits of applying production-related information technology architecture (PRITA) to produce a visual management system (VMS) within the manufacturing industry? This was investigated with set of objectives to support the research question and the outcome of each objective follows:

The first objective involved the process of investigating and defining VMS with the aim of developing a model for effective information communication and/or displaying. This was achieved by investigation into the needs of users that will benefit from using visual communication techniques and produced four VMS model elements. These elements were visualization tools for information conveying purposes, smart processing capabilities of information, user specific information sourcing and the convenience of mobile technologies and cloud computing. The first objective was achieved with the VMS model development and defining of VMS as a holonic data sourcing, processing and information displaying system with the goal of heuristic process understanding.

The second objective therefore involved the process of investigating PRITA systems that meet the prerequisites of VMS. The four VMS elements were then used as basis for further exploration into the next objective where the current technology solutions were investigated that can support the sourcing and processing of data from production processes. PRITAs provide the intermediate process of sourcing the data from manufacturing activities that can be generated by machinery or human operations. These four PRITAs were implemented within production environments to investigate the potential of the VMS model within the manufacturing industry. An investigation into the information handling capabilities was conducted to produce four PRITA systems that can support all the functionalities listed as prerequisites of the VMS model. This process involved a correlation study into PRITA systems and the necessary functionalities of all four VMS elements. These correlations were then clustered according to strong function supporting characteristics to define four PRITAs that can support the four VMS elements data handling prerequisites. In doing so, completing the second objective.

The third objective was to develop case studies that investigate and validate the implementation capabilities of the developed PRITA and VMS model. Four case studies were developed that investigated the effectiveness of the VMS model with information communication. They were implemented in two academic production environments to produce controlled validation environments for the study and resemble SMEs of South Africa manufacturing industry. Case study one proved production KPIs can be displayed on dashboards using IoT technology. The second case study proved that smart algorithms can be applied to sourced data to display production line analytics on a dashboard output. The third case study proved that the automation pyramid architecture can be incorporated to provide user specific information on different managerial levels. The fourth case proved that mobile applications are capable of replicating current information capturing methods.

The fourth objective was to determine the influential or beneficial factors of VMS. The four previously mentioned case studies revealed that the VMS was considered an important value-adding element to the manufacturing industry with majority of the expert interview participants agreeing. VMS provided the functionalities of trend analytics that can give information regarding the operational condition of production and making conservative predictions of the production cycle analysis. Investigation into modernisation of the traditional methods of information communication through the organisation was introduced with the VMS model and researched with the use of mobile technology and cloud computing.

The research found that the PRITA and VMS model was implementable within the manufacturing industry using limited funding and open source and/or freeware IoT solutions can be achieved. It successfully investigated the sourcing of production data to produce digital visualization of production KPI information that is dynamically updated as new data sets are presented. It also investigated methods of improving information communication within an organisation to improve on the traditional downward flow to a modern upwards flow with processing and storing levels for increased transparency and control of production process on the shop floor.

5.1.2 *Limitations of the Research*

Currently the future of technology incorporation into the manufacturing industry looks very promising. These new technologies will allow increased knowledge development in the production process. VMS will provide the solution to understanding and relating the information to improve on the traditional flow of information. This new method will involve an increased amount of data collection on lower operation levels from which the information can flow up through managerial levels to eventually produce action items and information flowing down the model again. A number of limitations influenced the research outcome, which were mostly technical issues that were discussed in the literature study, but became problematic as the research progressed. Here are the three major limitations:

1. Seeing that this research was carried out in a South African context, all the PRITAs or development tools used to develop the case studies were open-source or freeware solutions.
2. The development and integration of the case studies was not based on plug-and-play principles of future technology. Rather, the case studies took some time to develop and the integration included complicated methods of programming application interfaces.
3. Concurrent design and general acceptance of this methodology will generally change in the near future due to technological improvements. Therefore, this study is limited to the current model.

These limitations became apparent as the research progressed. The development of a universal IoT architecture of sourcing and communicating data will greatly reduce the initial investment costs of implementation for user specific solutions. The unification of universality and implementation would make the growth of VMS incorporation into any industry more achievable. With this universal architecture, the security and stability issues of the technology could be addressed as well.

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APPENDIX A: SLF DATA LOGGER TECHNICAL SPESIFICATION REPORT

This appendix details the process of creating the data logging device that was used to scan the RFID tags on the work-in-progress SLF containers. The ESP8266 Wi-Fi module and the AdaFruit RFID scanner setup is discussed and the necessary code to run these components on the Arduino Uno Microprocessor is provided.

Arduino Data Logger v0.1

Introduction

In this document the steps will be discussed to create the data logger as used in the thesis by Lukas Steenkamp. The necessary preparations and initializing steps is to follow and then the entirety of the steps to develop the visual management tool or dashboard developed with Google Sheets, Arduino UNO, ESP8266 and PushingBox. The youtube.com tutorial, Arduino Data Logging to Google Docs (Spreadsheet), can be found following this link: https://www.youtube.com/watch?v=fVBqUeksR1I

Updating the ESP8266

In this section the process of updating the ESP8266 Wi-Fi module is explained. This step is necessary to enable more functions and therefore create a more stable final communication platform.

1. Firstly you will need to wire the ESP8266 for Flash Mode.

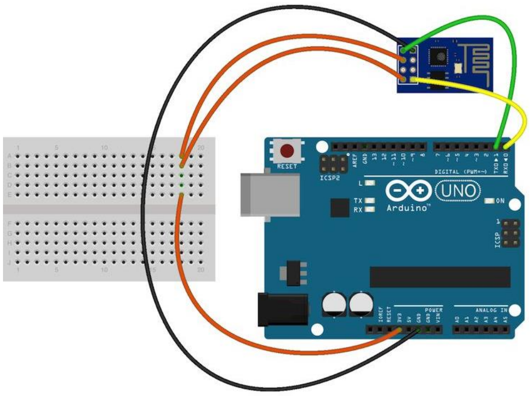


Figure 1: Wiring demonstration when flashing ESP8266

2. Download the flashing software and the latest firmware for the ESP8266.
    a. Firmware: https://drive.google.com/file/d/0B3dUKfqzZnlwdUJUc2hkZDUyVjA/view?usp=sharing/
    b. Flashing Software: http://www.xess.com/blog/esp8266-reflash/
3. Browse the bin file or firmware version files and also check the correct com port of the Arduino.
4. Then just click download button, if everything is fine the flasher will show you the status of download and also your ESP8266 module led will blink very fast.
5. In the end at 99% it will show some error but this is fine. You have uploaded latest firmware to ESP8266.
6. IT's time to test your ESP8266module .now just remove GPIO 0 wire that was connected to GND, you can connect it to VCC or leave it like this.
7. Now plug your Arduino back to pc and open serial port.
8. Open 9600 baud rate, most of the ESP8266 works fine on this baud rate.
9. NOW it's time to test AT commands .enter "AT" in serial port and you will get "OK". Now enter "AT+GMR" and check the firmware version.
10. Congratulations, you have successfully updated the firmware of the ESP8266.

The example used for this explanation came from an Instructables page entitled *Esp8266 firmware update*. Follow this link or copy the following into your browser:
http://www.instructables.com/id/Intro-Esp-8266-firmware-update/

Or another good instructions page is the Reflash Dance page: http://www.xess.com/blog/esp8266-reflash/

Soldering the Circuit

In this section the circuit and the connections will be discussed together with iterations in the design to improve performance of the ESP8266 Wi-Fi Module. In the pin layout of the module can be seen.

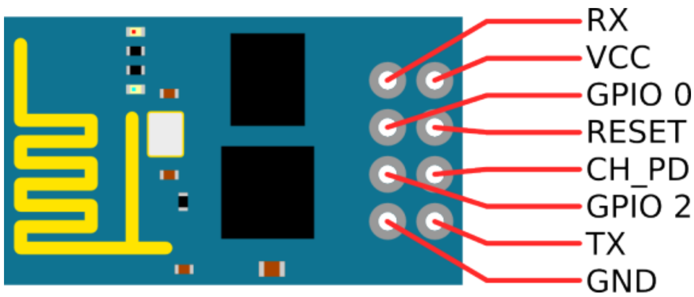


Figure 2: ESP8266 module pin descriptions

Now the connections between the Arduino UNO and the ESP8266 will be discussed after Figure 3 that demonstrates the connections.

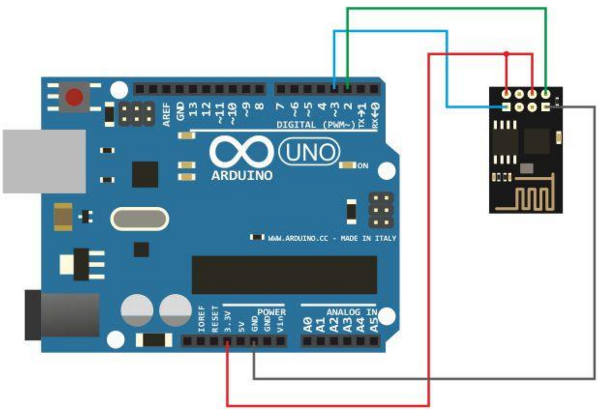


Figure 3: Wiring of ESP8266 demonstrating working condition

Descriptions and notes regarding the circuits:

1. Firstly and most importantly, the ESP8266 has an input voltage of 3.3V. When 5V is applied this will burn out the component. Therefore the 3.3V is applied to ESP8266 Vcc and CH_PD.
2. Ground is connected ground of both components.
3. Communication between these components will make use of the UART communication protocol. Important to note here will be that communication happens between the transmit pin and the receive pin, and receive and transmit pin of the respective components. It will therefore not work if transmit and transmit, for instance, is connected together.

Updates to the circuit (source: http://internetofhomethings.com/homethings/?p=396/):

1. The circuit made use of pin 2 and pin 3 for the transmit and receive pin to avoid communication errors if or when new software are updated to the Arduino UNO. Unfortunately, the final design did make use of pin 0 and 1 that is the designated communication pins and was therefore required to be disconnected when new code is uploaded.
2. Two capacitors were added between Ground and Vcc to produce a more stable power supply to the ESP8266. One was a small 0.1 uF decoupling capacitor across the ESP8266 Vcc to Ground inputs very close to the pins. The other was a large capacitor (suggest using 470 uF) across the Vcc to Ground that will minimize reset inducing voltage fluctuations.
3. The power source should be an external source that can supply the necessary current to the Wi-Fi module. At least 500mA is requited and the Arduino can only supply less than half that.

RFID shield

For this design an Adafruit RFID Shield was used and a picture of it on the Arduino UNO can be seen in

Figure 3: Actual Arduino UNO, Adafruit RFID scanner and ESP8266 module

Online Accounts and Setup Instructions

In this section, the Google Sheet and PushingBox will be discussed. Some of the settings and extra steps are explained to make sure all the online accounts work together. The reason for using PushingBox to post data to Google Sheets are for the reason that the Arduino cannot post directly. Therefore Google Sheets will first be discussed and there afterwards the PushingBox setup.

Create a new or use an existing Google Account for the following steps:

1. Create a folder in Google Drive and name it Project, then create a Google Sheet in this folder and name it DataLogger.
2. Open the DataLogger Sheet and in the first block, block A1, type in TimeStamp. In the second block next to it, type DataValue.

3. Now you must connect the Google App Script to your account. To do this you go back to Google Drive and open the Project folder you created earlier. Now click on New, then click on more and then click on Connect More Apps.
4. In the new window type in the search bar: Google App Script. Then press connect. Then press OK.
5. Go back to the Project folder in Google Drive and click on new, then more then on Google App Script. A new tab will appear will look like an empty code block, copy and paste the following:

```
/* Using spreadsheet API */ //
https://script.google.com/macros/s/AKfycbwLEjpFFpegXPLpaii8MTS6-lLc2gJj-
D82zlFHpuw9qatQ8oBy/exec?tempData=datahere

function doGet(e) {
  Logger.log( JSON.stringify(e) );  // view parameters

  var result = 'Ok'; // assume success

  if (e.parameter == undefined) {
    result = 'No Parameters';
  }
  else {
    var id = '15kUys96xC17riiKuy779MVCSkT3qoCttBah9zwipYDg'; // Spreadsheet ID
    var sheet = SpreadsheetApp.openById(id).getActiveSheet();
    var newRow = sheet.getLastRow() + 1;
    var rowData = [];
    //var waktu = new Date();
    rowData[0] = new Date(); // Timestamp in column A
    for (var param in e.parameter) {
      Logger.log('In for loop, param='+param);
      var value = stripQuotes(e.parameter[param]);
      //Logger.log(param + ':' + e.parameter[param]);
      switch (param) {
        case 'tempData': //Parameter
          rowData[1] = value; //Value in column B
          break;
     // case 'column_C':
       // rowData[2] = value;
       // break;
        default:
          result = "unsupported parameter";
      }
    }
    Logger.log(JSON.stringify(rowData));

    // Write new row below
    var newRange = sheet.getRange(newRow, 1, 1, rowData.length);
    newRange.setValues([rowData]);
```

```
  }

  // Return result of operation
  return ContentService.createTextOutput(result);
}

//Remove leading and trailing single or double quotes
function stripQuotes( value ) {
  return value.replace(/^["']|['"]$/g, "");
}
```

---

6. Click File and then click on save. Change the Name to GoogleSheetAPI.
7. Go back to Google Drive and open the DataLogger Google Sheet that you created earlier, here we would like to copy the sheet ID that is displayed in the browser. For instance if your sheet is the following, your sheet ID will be the grey highlighted bit between the backslashes, copy this bit only: https://docs.google.com/spreadsheets/d/1jEZHNbvRtgYUEIdVI0y8KkFkSY_Ue6roigCrkJQtcok/edit#gid=0
8. Now go to the GoogleSheetAPI and paste this string of text in where the comments say spreadsheet id for responses. The line of code should thus look like this:
   var id = '1jEZHNbvRtgYUEIdVI0y8KkFkSY_Ue6roigCrkJQtcok '; // Spreadsheet ID
9. This finished the process of setting up the Google API.

Libraries and Code

```
#include <SoftwareSerial.h>

//---------Conditions for ESP8266 and Pushingbox-------------------------------------//
#define SSID       "Luka*******Pro"
#define PASS        "Las*****nect"

#define HOST        "api.pushingbox.com"
#define PORT        80//443 is for secure socket which seems not to be supported at this point on the
ESP8266

#define MAX_SERVER_CONNECT_ATTEMPTS 5

SoftwareSerial dbgSerial(0, 1); // (RX, TX)
//String sMessage_1 = "card1";

#define BUFFER_SIZE 512
char buffer[BUFFER_SIZE];
//int count = 30;

//---------Conditions for RFID Shield--------------------------------------------//
```

```
#include <Wire.h>
#include <SPI.h>
#include <Adafruit_PN532.h>

// If using the breakout with SPI, define the pins for SPI communication.
//#define PN532_SCK  (2)
//#define PN532_MOSI (3)
//#define PN532_SS   (4)
//#define PN532_MISO (5)

// If using the breakout or shield with I2C, define just the pins connected
// to the IRQ and reset lines.  Use the values below (2, 3) for the shield!
#define PN532_IRQ   (2)
#define PN532_RESET (3)  // Not connected by default on the NFC Shield

// Or use this line for a breakout or shield with an I2C connection:
Adafruit_PN532 nfc(PN532_IRQ, PN532_RESET);

#if defined(ARDUINO_ARCH_SAMD)
// for Zero, output on USB Serial console, remove line below if using programming port to program
the Zero!
// also change #define in Adafruit_PN532.cpp library file
   #define Serial SerialUSB
#endif

int cardid;

//---------Functions for ESP8266 Start and Restarting------------------------------//
// By default we are looking for OK\r\n
char OKrn[] = "OK\r\n";
byte wait_for_esp_response(int timeout, char* term=OKrn) {
  unsigned long t=millis();
  bool found=false;
  int i=0;
  int len=strlen(term);
  // wait for at most "timeout" milliseconds
  // or if OK\r\n is found
  while(millis()<t+timeout) {
    if(Serial.available()) {
      buffer[i++]=Serial.read();
      if(i>=len) {
        if(strncmp(buffer+i-len, term, len)==0) {
          found=true;
          break;
        }
      }
    }
  }
  buffer[i]=0;
```

```
  dbgSerial.println(buffer);
  return found;
}

byte StartModule()
{
  //reset and test if the module is ready
  bool module_responding =  false;
  bool connected_to_access_point = false;
  dbgSerial.println("Starting module");
  while(!module_responding){
    //software reset
    Serial.println("AT+RST");//reset module (works with both ESP-01 and ESP-03 module)

    if (wait_for_esp_response(5000, "ready")){ //watch out for the case of the r in ready - varies with
ESP8266 firmware version
      dbgSerial.println("Module is responding");
      module_responding = true;
    }
    else{
      dbgSerial.println("Module not responding to reset");
      delay(1000);
    }
  }
  //------------------------------------------------------------------------------------------------------------------

  Serial.println("AT+GMR");
  wait_for_esp_response(1000);

  Serial.println("AT+CWMODE=1");
  wait_for_esp_response(1000);

  Serial.println("AT+CIPMUX=0");
  wait_for_esp_response(1000);

  dbgSerial.println(F("Connecting to WiFi access point..."));
  String cmd = "AT+CWJAP=\"";
  cmd += SSID;
  cmd += "\",\"";
  cmd += PASS;
  cmd += "\"";
  dbgSerial.println(cmd);
  Serial.println(cmd);
  connected_to_access_point = wait_for_esp_response(9000);
  if(!connected_to_access_point){
    dbgSerial.println(F("Attempt to connect to access point failed. Restarting module."));
    return false;
  }
  else
```

```
  {
    dbgSerial.println(F("CONNECTED TO ACCESS POINT"));
  }

  //}
  bool connected_to_dweet = false;
  int connection_attempts = 0;
  dbgSerial.println(F("Connecting to dweet..."));
  while((!connected_to_dweet)&&(connection_attempts <
MAX_SERVER_CONNECT_ATTEMPTS)){
    cmd = "AT+CIPSTART=\"TCP\",\"";
    cmd += HOST;//"www.dweet.io";
    cmd += "\",";
    cmd += PORT;
    Serial.println(cmd);
    dbgSerial.println(cmd);
    connected_to_dweet = wait_for_esp_response(9000);//this needs to change - look for  something
in server response that indicates valid connection
    connection_attempts += 1;
    if (!connected_to_dweet)
    {
      dbgSerial.println(F("Attempt to connect to dweet did not succeed"));
    }
    else
    {
      dbgSerial.println(F("CONNECTED TO DWEET"));
    }
  }
  return connected_to_dweet;
}

//---------Setup and Loop functions-------------------------------------------//
void setup()
{
//Setup module hardware for esp8266------------------------------

  Serial.begin(115200);
  //Serial.setTimeout(5000);
  dbgSerial.begin(115200);//(4800);//9600);  //consider baud limitations for software serial
  Serial.println("ESP8266 dweet.io & freeboard.io Example - www.8266.rocks");

  while(!StartModule()){
    delay(1000);
    dbgSerial.println(F("***Calling StartModule Again***"));
  }

  delay(5000); // this is a bandaid for the delayed "linked" response from some firmware versions for
the ESP-03
```

```
  Serial.println("Hello!");

  nfc.begin();

  uint32_t versiondata = nfc.getFirmwareVersion();
  if (! versiondata) {
    Serial.print("Didn't find PN53x board");
    while (1); // halt
  }

  // Got ok data, print it out!
  Serial.print("Found chip PN5"); Serial.println((versiondata>>24) & 0xFF, HEX);
  Serial.print("Firmware ver. "); Serial.print((versiondata>>16) & 0xFF, DEC);
  Serial.print('.'); Serial.println((versiondata>>8) & 0xFF, DEC);

  // Set the max number of retry attempts to read from a card
  // This prevents us from waiting forever for a card, which is
  // the default behaviour of the PN532.
  nfc.setPassiveActivationRetries(0xFF);

  // configure board to read RFID tags
  nfc.SAMConfig();

  Serial.println("Waiting for an ISO14443A card");

}

void loop()
{
//waiting for card to be scanned---------------------------------
  boolean success;
  uint8_t uid[] = { 0, 0, 0, 0, 0, 0, 0 };  // Buffer to store the returned UID
  uint8_t uidLength;        // Length of the UID (4 or 7 bytes depending on ISO14443A card type)

  // Wait for an ISO14443A type cards (Mifare, etc.).  When one is found
  // 'uid' will be populated with the UID, and uidLength will indicate
  // if the uid is 4 bytes (Mifare Classic) or 7 bytes (Mifare Ultralight)
  success = nfc.readPassiveTargetID(PN532_MIFARE_ISO14443A, &uid[0], &uidLength);

  if (success) {
    Serial.println("Found a card!");
    Serial.print("UID Length: ");Serial.print(uidLength, DEC);Serial.println(" bytes");
    Serial.print("UID Value: ");
    for (uint8_t i=0; i < uidLength; i++)
    {
      Serial.print(uid[i]);
    }
    Serial.println("");
```

```
    cardid=uid[0]+uid[1]+uid[2]+uid[3];
    Serial.println("The card number");
    Serial.println(cardid);

    senddata();

    //if (cardid == 507) {
    //  Serial.print("card1");
    //}

    //Serial.print(cardid1);

  // Wait 1 second before continuing
  delay(1000);
  }
  else
  {
    // PN532 probably timed out waiting for a card
    Serial.println("Timed out waiting for a card");
  }
}

 void senddata(){
//check to see if esp is responding------------------------------

  //if (!wait_for_esp_response(9000,"> ")){
  //  Serial.println("AT+CIPCLOSE");
  //  dbgSerial.println("send timeout - resetting wifi module");
  //  delay(1000);
  //  StartModule();
  // }

//pushbox--------------------------------------------------------

  String cmdpost;

  cmdpost =  "GET /pushingbox?devid=";
  cmdpost += "vA8C1CBB864EBB07&tempData=";
  cmdpost += cardid;
  cmdpost += " HTTP/1.1\r\n";  //construct http GET request
  cmdpost += "Host: api.pushingbox.com\r\n\r\n";
  Serial.print("AT+CIPSEND=");
  Serial.println(cmdpost.length());  //esp8266 needs to know message length of incoming message
- .length provides this

  dbgSerial.print("AT+CIPSEND=");
  dbgSerial.println(cmdpost.length());

  if (!wait_for_esp_response(9000,"> ")){
```

```
    Serial.println("AT+CIPCLOSE");
    dbgSerial.println("send timeout - resetting wifi module");
    delay(1000);
    StartModule();
   }

  delay(1000);

  Serial.println(cmdpost);  //this is our http GET request
  dbgSerial.println(cmdpost);  //this is our http GET request

  delay(1000);
  //Serial.println("AT+CIPCLOSE");
  //count++;
}
```

APPENDIX B: SLF VMS CASE STUDY QUESTIONAIIRE - VISUALISATION TOOLS

This appendix illustrates the screenshots of the SLF VMS questionnaire that was compiled to validate the first case study. It details the longitudinal research method of questioning the participant was introduced to gather the required information. Figures 1 to 5 illustrates the flow of questions and the information presented before each question. Table 1 captures the responses from the RPD lab and STC-LAM academics, industry representatives and lab personnel when introduces to just raw tabled data. Table 2 captures the responses of the participants after the VMS dashboard is introduced. In doing so, providing the difference over time of the participants' responses.

Visual Managment System Questionnaire: Stellenbosch Learning Factory

Introduction and Accepting to do questionnaire.

Hello,

My research involves the implementation of visual management systems within smart production systems,

which basically involves added real-time feedback of production processes using graphs and then adding intelligence to see if it can improve production.

As per usual, you have a choice to complete this questionnaire and as stated by the ethical committee (SU-HSD-002331) you may say no and/or at any time choose to withdraw. Nothing personal is asked, just super easy and nerdy one-liner questions. I promise.

The method of how this questionnaire will conducted is a before and a after opinion of the need for visual management system called a longitude design method.

Next.

Visual Managment System Questionnaire: Stellenbosch Learning Factory

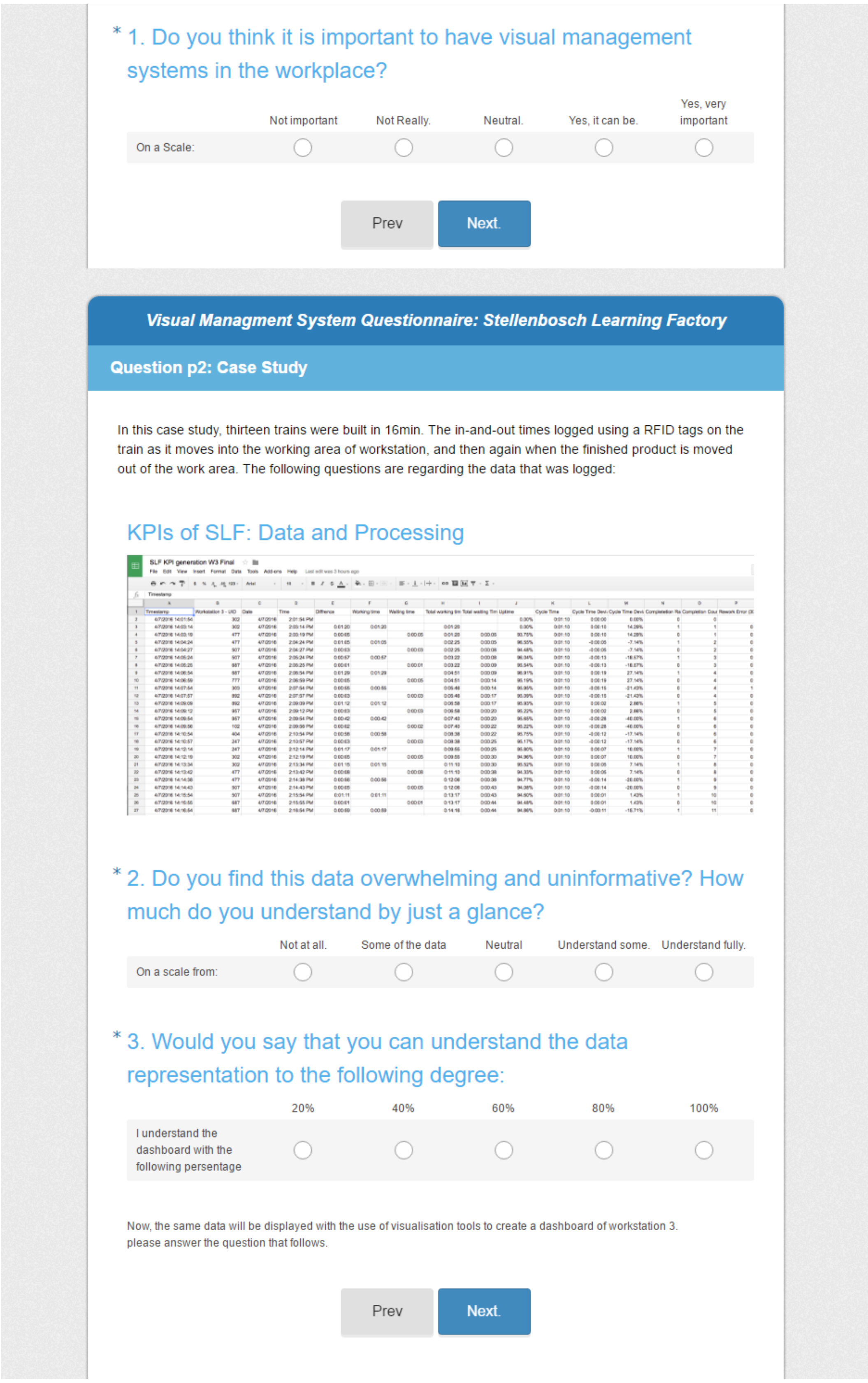
Question p1: Workstations 3 Example

Workstation 3, pictured below, is an example of a production line where model trains are built. Every 70seconds this station completes a train and then sends it for quality checkin and packaging. In comparison, Mercedes finishes a car every 90seconds.

Now visual management tools are incorporated to monitor key performance indicators (KPIs) of the production process and is implemented for the use of both the user of the workstation and the manager of a shop floor. Common KPIs are Uptime, Cycle Time, Scrap and Rework Count and Productivity.

Workstation 3: Final Train Assembly Workstation

Figure 1: First screenshot of the SLF VMS questionnaire



* 1. Do you think it is important to have visual management systems in the workplace?

	Not important	Not Really.	Neutral.	Yes, it can be.	Yes, very important
On a Scale:	○	○	○	○	○

Prev Next.

Visual Managment System Questionnaire: Stellenbosch Learning Factory

Question p2: Case Study

In this case study, thirteen trains were built in 16min. The in-and-out times logged using a RFID tags on the train as it moves into the working area of workstation, and then again when the finished product is moved out of the work area. The following questions are regarding the data that was logged:

KPIs of SLF: Data and Processing

* 2. Do you find this data overwhelming and uninformative? How much do you understand by just a glance?

	Not at all.	Some of the data	Neutral	Understand some.	Understand fully.
On a scale from:	○	○	○	○	○

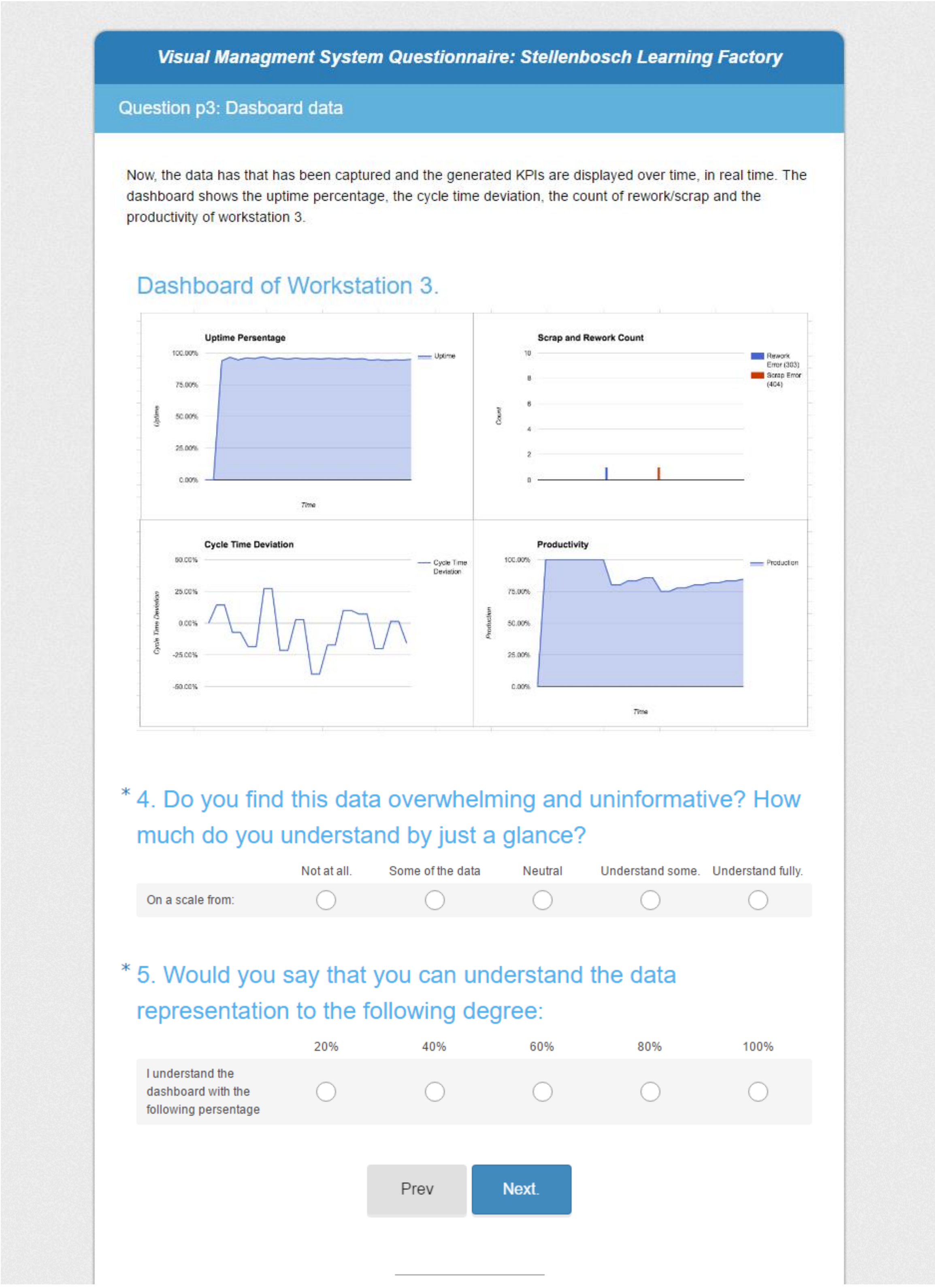
* 3. Would you say that you can understand the data representation to the following degree:

	20%	40%	60%	80%	100%
I understand the dashboard with the following persentage	○	○	○	○	○

Now, the same data will be displayed with the use of visualisation tools to create a dashboard of workstation 3. please answer the question that follows.

Prev Next.

Figure 2: Second screenshot of the SLF VMS questionnaire


Visual Managment System Questionnaire: Stellenbosch Learning Factory

Question p3: Dasboard data

Now, the data has that has been captured and the generated KPIs are displayed over time, in real time. The dashboard shows the uptime percentage, the cycle time deviation, the count of rework/scrap and the productivity of workstation 3.

Dashboard of Workstation 3.

* 4. Do you find this data overwhelming and uninformative? How much do you understand by just a glance?

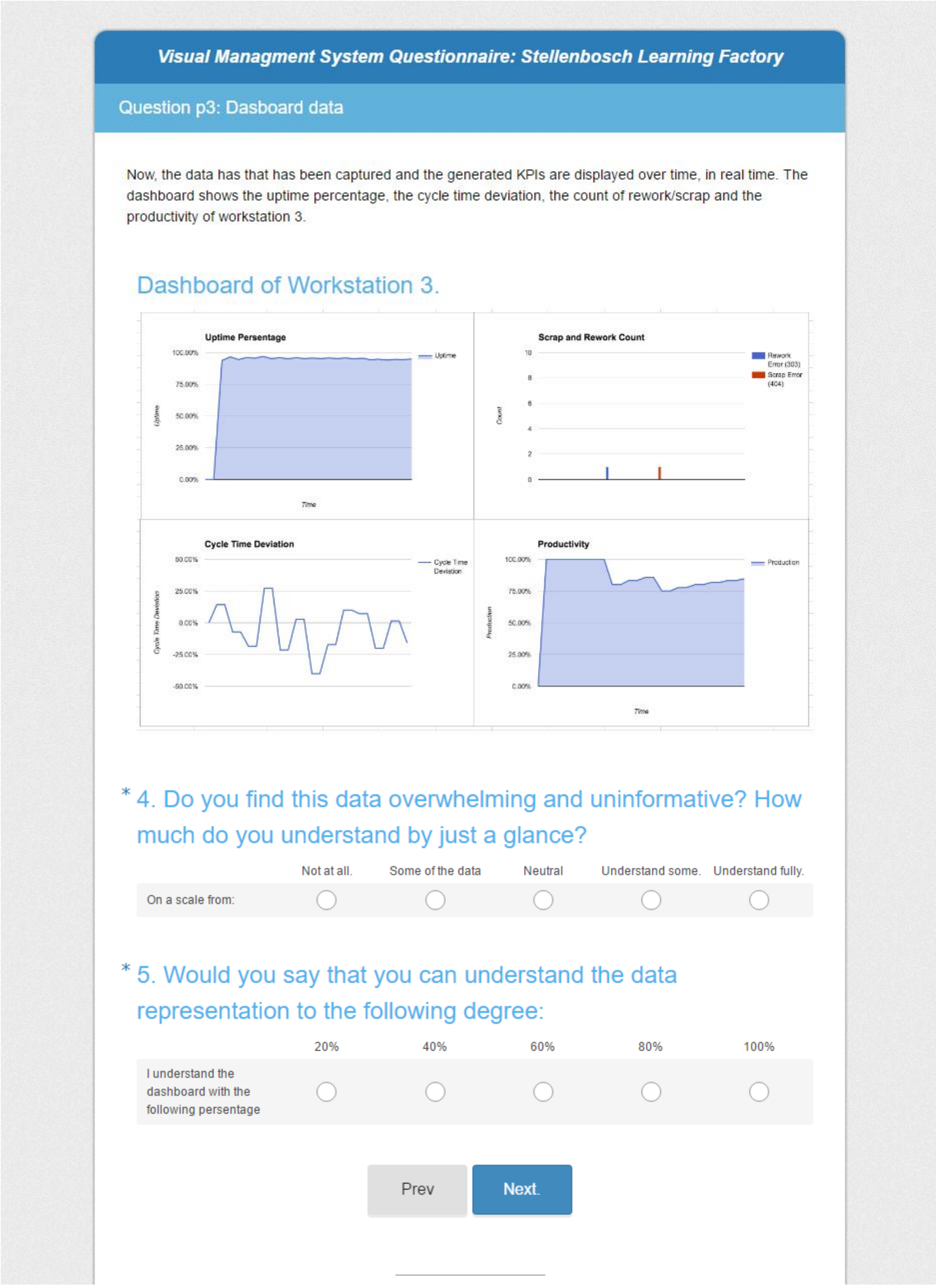
	Not at all.	Some of the data	Neutral	Understand some.	Understand fully.
On a scale from:	○	○	○	○	○

* 5. Would you say that you can understand the data representation to the following degree:

	20%	40%	60%	80%	100%
I understand the dashboard with the following persentage	○	○	○	○	○

Prev Next

Figure 3: Third screenshot of the SLF VMS questionnaire



Visual Managment System Questionnaire: Stellenbosch Learning Factory

Question p3: Dasboard data

Now, the data has that has been captured and the generated KPIs are displayed over time, in real time. The dashboard shows the uptime percentage, the cycle time deviation, the count of rework/scrap and the productivity of workstation 3.

Dashboard of Workstation 3.

* 4. Do you find this data overwhelming and uninformative? How much do you understand by just a glance?

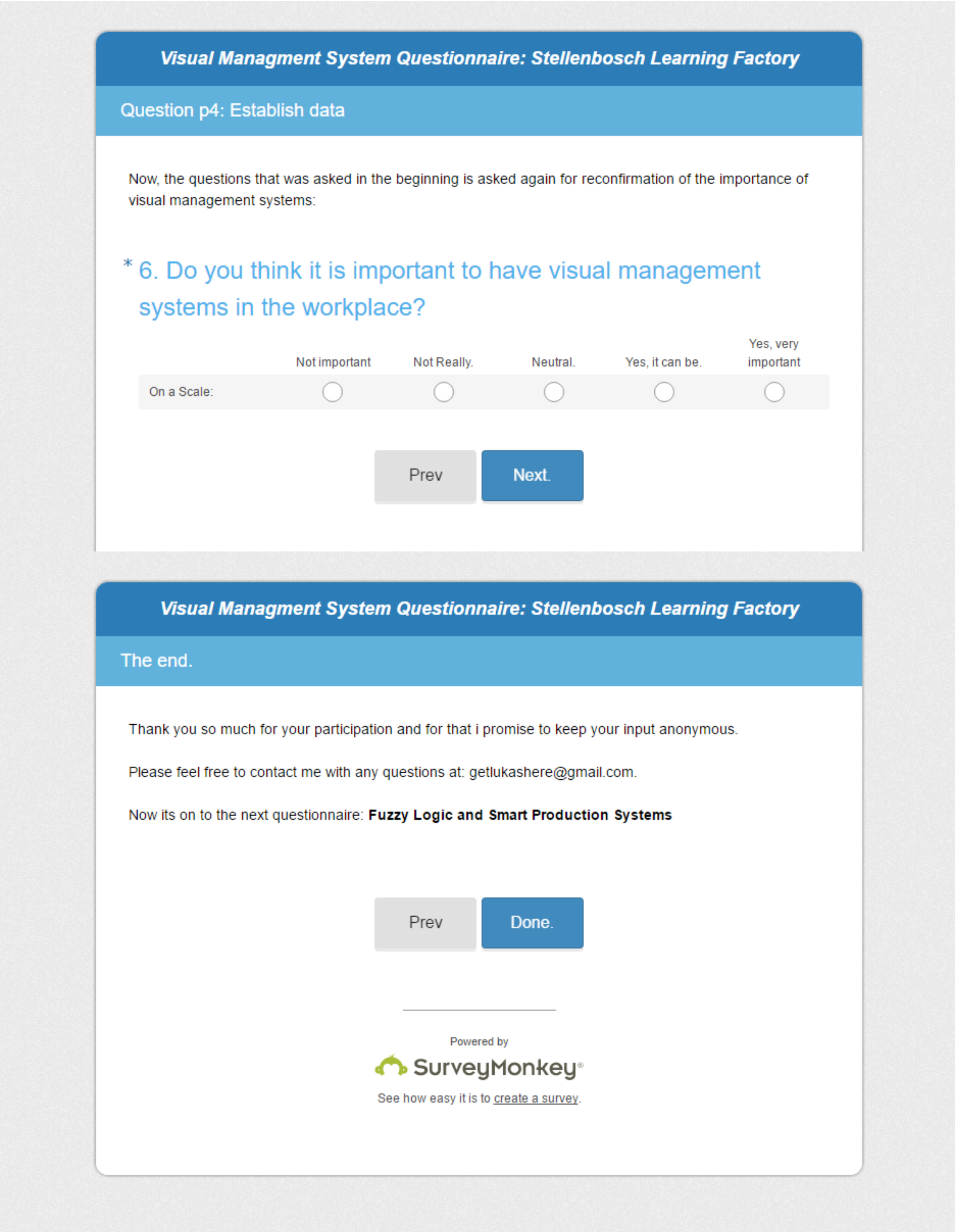
	Not at all.	Some of the data	Neutral	Understand some.	Understand fully.
On a scale from:	○	○	○	○	○

* 5. Would you say that you can understand the data representation to the following degree:

	20%	40%	60%	80%	100%
I understand the dashboard with the following persentage	○	○	○	○	○

Prev Next

Figure 4: Fourth screenshot of the SLF VMS questionnaire



Visual Managment System Questionnaire: Stellenbosch Learning Factory

Question p4: Establish data

Now, the questions that was asked in the beginning is asked again for reconfirmation of the importance of visual management systems:

* 6. Do you think it is important to have visual management systems in the workplace?

	Not important	Not Really.	Neutral.	Yes, it can be.	Yes, very important
On a Scale:	○	○	○	○	○

Prev Next.

Visual Managment System Questionnaire: Stellenbosch Learning Factory

The end.

Thank you so much for your participation and for that i promise to keep your input anonymous.

Please feel free to contact me with any questions at: getlukashere@gmail.com.

Now its on to the next questionnaire: **Fuzzy Logic and Smart Production Systems**

Prev Done.

Powered by SurveyMonkey®

See how easy it is to create a survey.

Figure 5: Fifth screenshot of the SLF VMS questionnaire

Table 1: Responses of the SLF VMS questionnaire before VMS introduction

1	Do you think it is important to have VMS in the workplace?				
	Not important	Not really important	Neutral	Somewhat important	Really important
	0	0	0	8	6
2	Do you find this data representation overwhelming and uninformative? How much do you understand with just a glance?				
	Nothing	Somewhat	Neutral	Most of it	Everything
	0	5	3	6	0
3	To what degree or percentage do you understand this data representation style?				
	20%	40%	60%	80%	100%
	1	2	7	4	0

Table 2: Responses of the SLF VMS questionnaire after VMS introduction

4	Do you find this data representation overwhelming and uninformative? How much do you understand with just a glance?				
	Nothing	Somewhat	Neutral	Most of it	Everything
	0	1	0	7	6
5	To what degree or percentage do you understand this data representation style?				
	20%	40%	60%	80%	100%
	0	0	3	5	6
6	Do you think it is important to have VMS in the workplace?				
	Not important	Not really important	Neutral	Somewhat important	Really important
	0	0	1	3	10

APPENDIX C: SLF VMS CASE STUDY QUESTIONAIIRE – FUZZY LOGIC

This appendix illustrates the questionnaire screenshots used in the longitudinal research method to produce the validation of the second case study that demonstrated the use of smart production systems within SLF production line setup. Figure 1 to 5 illustrates the flow of questions and the information presented to the participants as the questionnaire progressed. Table 1 and 4 represent the participants before and after response of the use of smart production systems within the manufacturing industry. Table 2 compares the current KPI dashboard to the fuzzy logic dashboard extension to the participants to capture their responses for the perfect run case. Then Table 3 compares the participants' responses of the fault count introduction on the same dashboard.

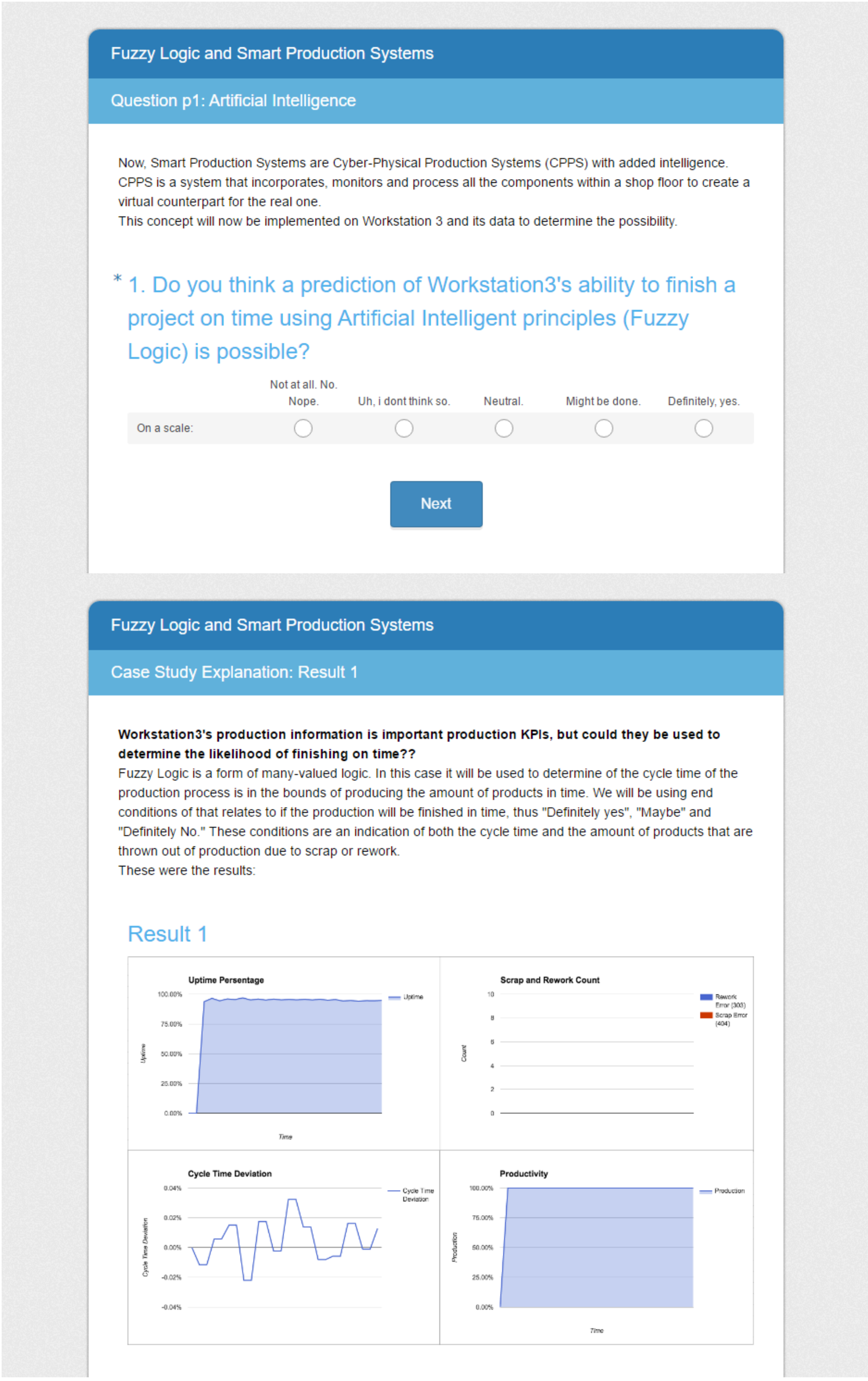


Figure 1: First screenshot of the SLF VMS's second case questionnaire

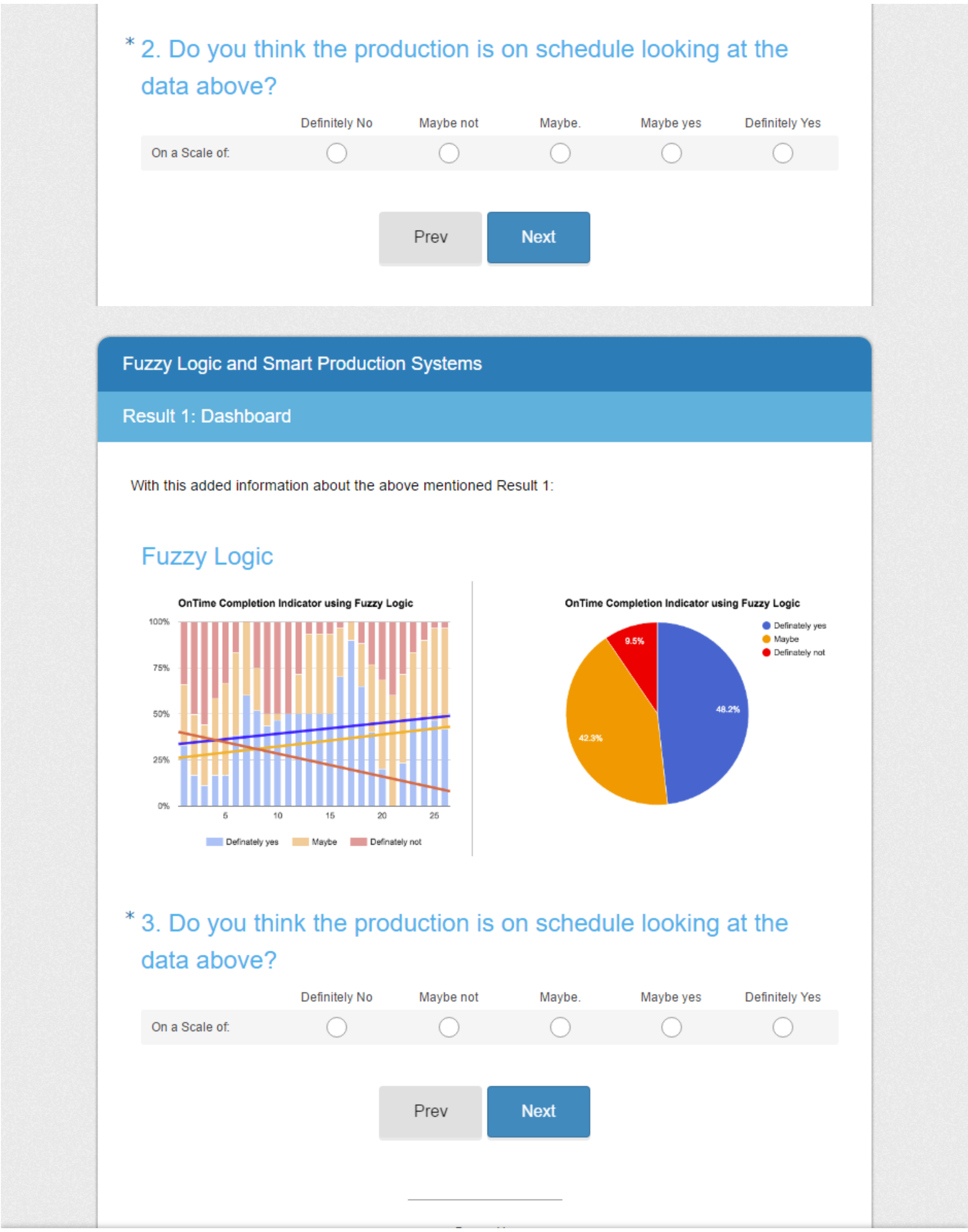


Figure 2: Second screenshot of the SLF VMS's second case questionnaire

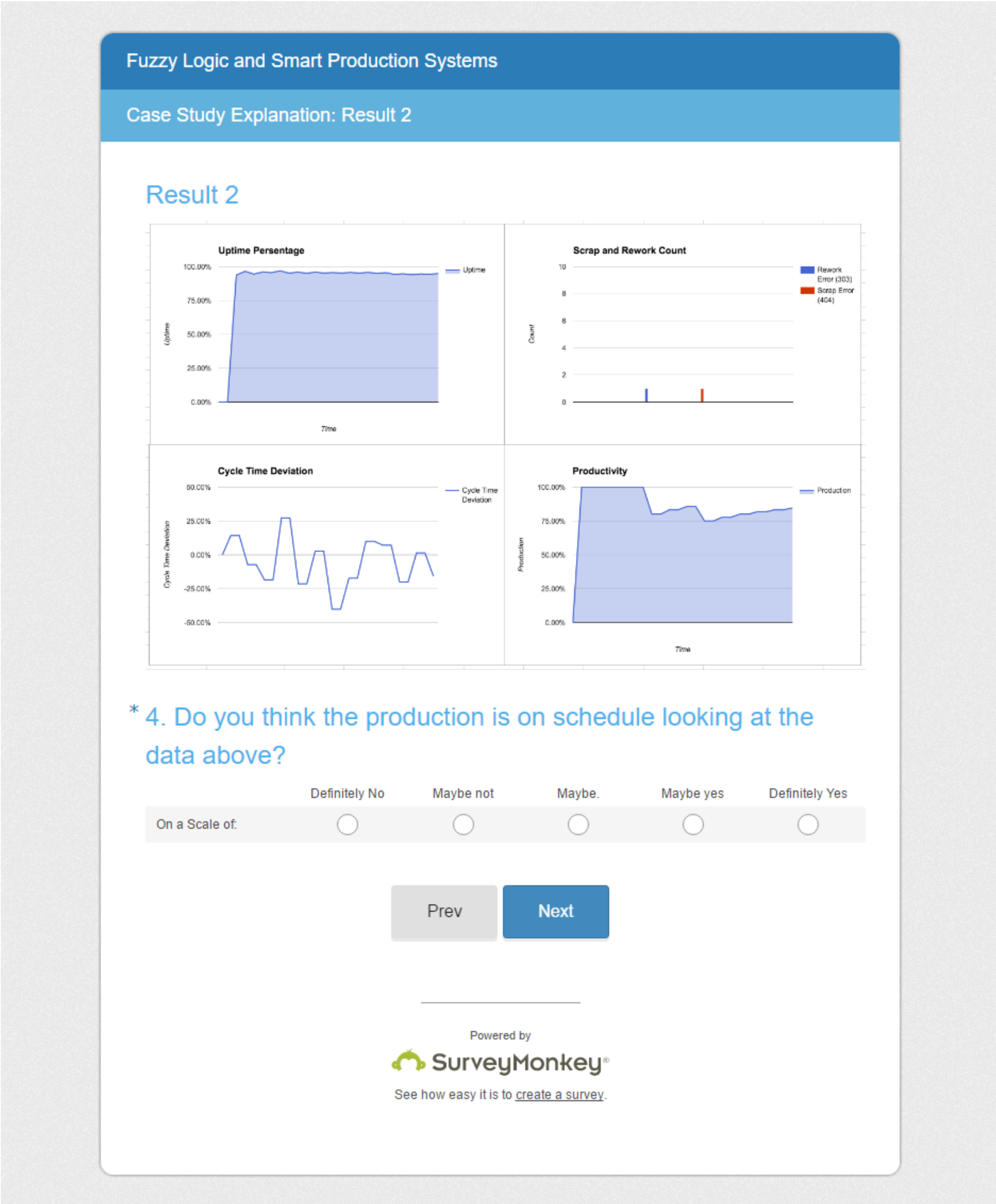


Figure 3: Third screenshot of the SLF VMS's second case questionnaire

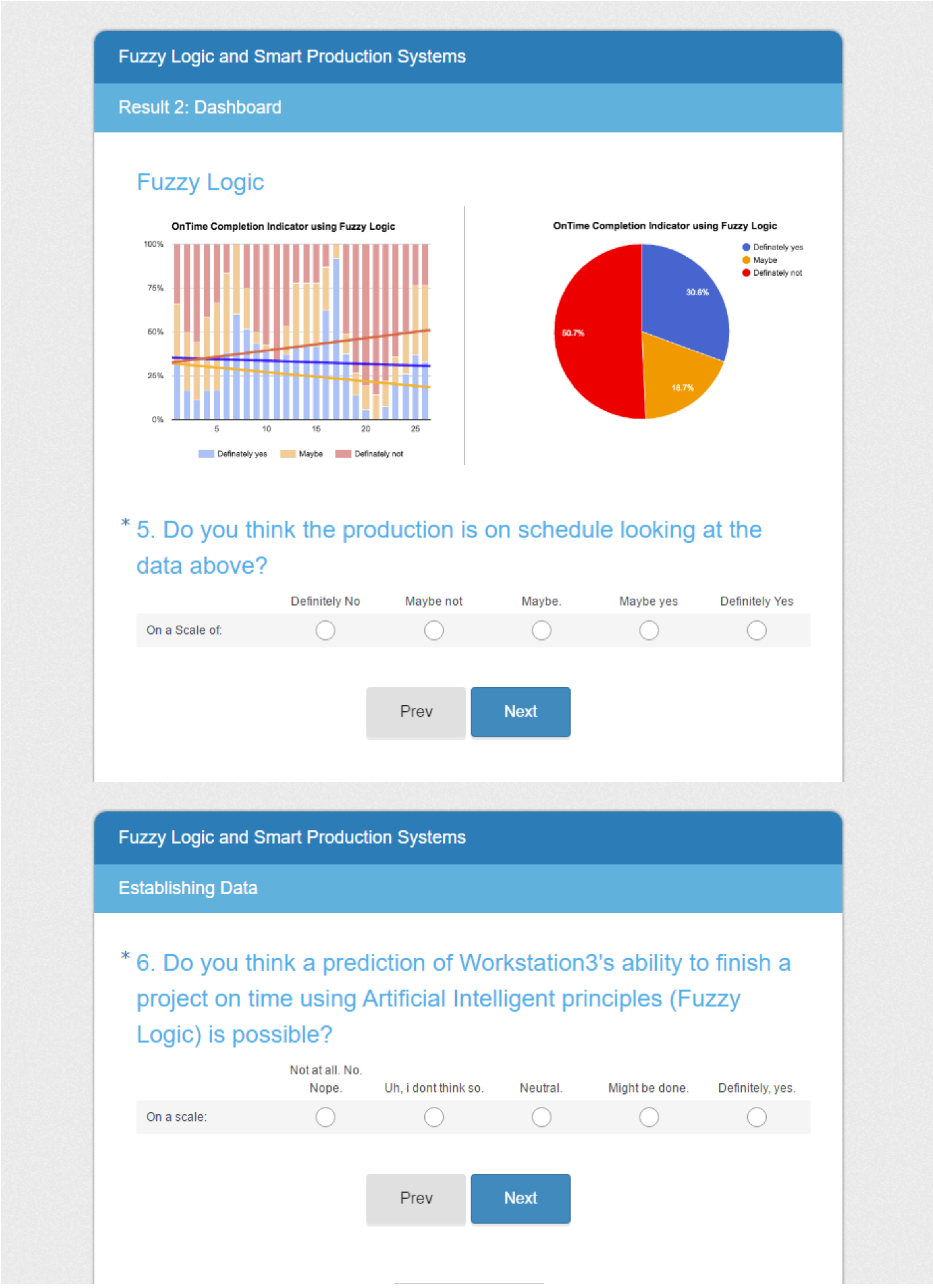


Figure 4: Fourth screenshot of the SLF VMS's second case questionnaire

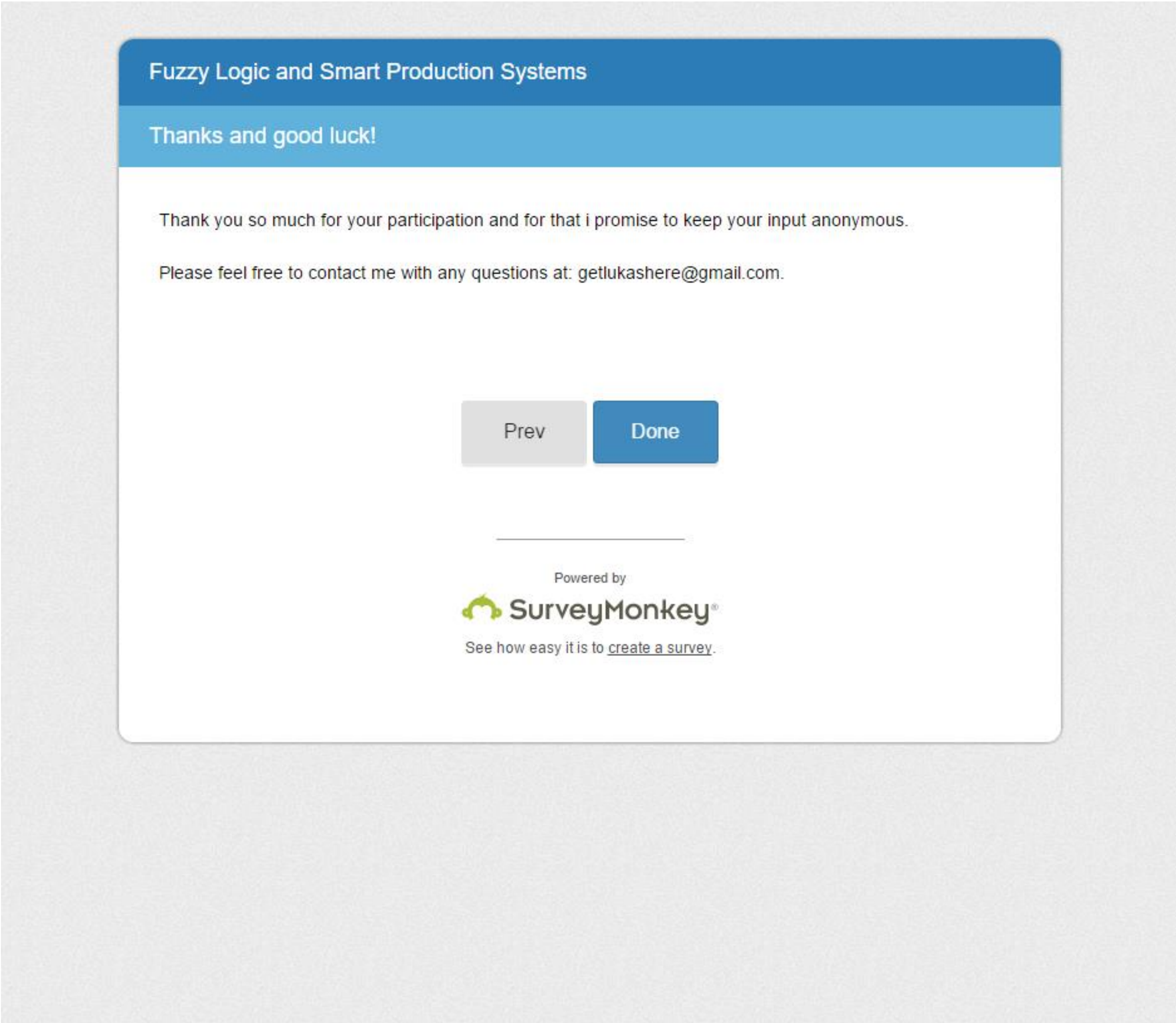


Figure 5: Last screenshot of the SLF VMS's second case questionnaire

Table 1: Responses of the SLF VMS questionnaire results before VMS's smart production system introduction

1	Do you think a prediction of workstatiion3's ability to finish a project on time using AI principles (Fuzzy Logic) is possible?				
	Not capable at all	Don't think so	Neutral	Might be capable	Definitely yes
	0	1	1	9	3

Table 2: Responses of the SLF VMS questionnaire results after introduction to the fuzzy logic fault count run dashboard

2	Do you think the production line is on schedule while looking at the data set above?				
	Definitely no	Maybe not	Neutral	Maybe yes	Definitely yes
	0	0	2	5	6
3	Do you think the production line is on schedule while looking at the data set above?				
	Definitely no	Maybe not	Neutral	Maybe yes	Definitely yes
	0	2	4	6	1

Table 3: Responses of the SLF VMS questionnaire results after introduction to the fuzzy logic perfect run dashboard

4	Do you think the production line is on schedule while looking at the data set above?				
	Definitely no	Maybe not	Neutral	Maybe yes	Definitely yes
	1	7	3	2	0
5	Do you think the production line is on schedule while looking at the data set above?				
	Definitely no	Maybe not	Neutral	Maybe yes	Definitely yes
	3	6	1	0	1

Table 4: Responses of the SLF VMS questionnaire results after VMS's smart production system introduction

6	Do you think a prediction of workstatiion3's ability to finish a project on time using AI principles (Fuzzy Logic) is possible?				
	Not capable at all	Don't think so	Neutral	Might be capable	Definitely yes
	0	1	0	10	2

APPENDIX D: STC-LAM INTERVIEW WITH RPD LAB RESEARCH GROUP

Here the value adding factors and reasons or comments are listed that was captured in a discussion with the STC-LAM and RPD research group. The information indicates opportunities and niches that can be investigated with VMS within the IoT and manufacturing scope.

Table 1: STC-LAM and RPD research group responses on IoT and related technology

Value Adding	Reason or comments
Convenience and User Friendly	Easy to learn, edit and manage the system,
	Does not require much effort,
	Quick and easy for setup purposes.
Future Schedule	Future job details, material and machines
	Academic tests and result purposes
	Resource management
Capacity and Capabilities	Specifications of the machines
	Materials that could be machined
	Cycle times of products
Real-time update	Necessary for scheduling accuracy
	Update accessibility
	Possibly per minute updates
Online CAD file submission	Online database creation
	Online feedback and update of CAD files
	Ease the communication between parties
Improve Communication	Better mutual understanding of the job outcome
	Online platform for comments on jobs
	Better communication builds better moral
Current Jobs and Linked Projects	Current jobs in process
	Projects and jobs that compliments each other
	Better picture of production processes
Progress Reports or Progress Percentage of completion	Improved job completion control
	Update all parties of the process
	Completion of desired time period
Estimated Job Lengths	Cycle time estimation
	Better Scheduling of resources
	Better pricing/quote estimations
Costing Mechanism	Improved project definition
	Improve administration at the start of project
	CAM software upgrade
Transparency of Processes	Better comprehension of processes
	Simplify administration at the start of project
	Improved mutual expected outcome
Help to Design to Manufacture	Comprehension of job steps
	Quicker and more accurate results
	Ease initial communication of machine capabilities
Requirements of Job Submissions	Ease communication between parties
	Create online submission platform
	List of checkpoints necessary for job information
Overall Equipment Effectiveness	Software installation that monitors equipment
	Improve resource effectiveness
	Could add value to ERP level
Availability and Usage of Machines	Improved scheduling
	Improve smaller job completion
	Resource management improvement
KPI's of Production	Could assess workshop better
	KPI's provide more information about processes
	Important for overall improvements
Calendar of Human Resources	Specific duties/task outline of human resources
	Improved human resource scheduling
	Performance monitoring

APPENDIX E: IAT CLIENT CAPTURING FORM

This appendix contains the Client Capturing Form that is used by the IAT team to collect project information from the potential client and then is used to assign an operational manager and technician that will oversee the project completion process.

Institute for Advanced Tooling
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technology innovation A G E N C Y

QAF:001 FOR EXTERNAL USE ONLY

ENQUIRES RECEIVED AND TENDERS SUBMITTED FORMAT

PERSONAL DETAILS						
Enquiry Receipt Date:		Enquiry No:				
First Name(s):		Title:	Mr.	Mrs	Dr.	Other
Last name		Nationality:				
ID Number:		Gender:	Male	Female		
Are you disabled?	Yes	No	Type of Disability			

CONTACT DETAILS
Address Line 1:
Address Line 2:
Area Code:
Email Address:
Telephone Number:
Fax Number:
Website:

BUSINESS DETAILS				
Business Name:				
Business Type:	cc	Pty	Sole Prop	Co-op
Registration Number:				
Tax Number:				
Tax Clearance	YES	NO		
Number of employees	Females	Males		
Annual Turnover				
Business Profile:	SME	LARGE	HEIS/Science Councils	Techno/Start-Entrepreneur
Business Profile (if other):				

SERVICES OFFERED BY TECHNOLOGY STATION	
Testing/Analysis	
Manufacturing/Prototyping	
Consultation/Audit	
Projects: CAD Design	
Projects: R&D (Thesis)	
Demonstration& Training	

DESCRIPTION OF ENQUIRY/IDEA

QUOTED AS PER/INFORMATION PROVIDED				
DRAWING	CAD DATA	TRAINING	SAMPLE	OTHERS

WHAT IS THE IMPACT ON CLIENT	
Export facilitated	
Employment secured	
Productivity	
Large Market	
Technology Innovation	

EXPECTATION ON PRODUCTION/PROCESS	
SABS Approval	
Quality Standards	
Compliance	
Green Technology	
Ability to perform practical application after training	

Client Signature:

Will we be submitting a tender? YES NO

If no tender is being submitted, has the client been notified in a form of a letter? YES NO IF NO, ATTACH MEETING FORM QAF 080

Has the tender to be submitted been carefully reviewed according to the enquiry and any different requirements brought to the attention of the client? YES NO

Commercial Requirement (FUNDING) CLIENT CONTRIBUTION	R ________________		
Operation Manager	Signature ____________________	Date ____________________	
Technologist Name ________________	Signature ____________________	Date ____________________	

Figure 1: Client Capturing Form of IAT

APPENDIX F: MOBILE APPLICATION RESEMBLING THE IAT CLIENT CAPTURING FORM

This appendix displays the mobile application created to resemble the IAT client capturing form of the previous appendix. The screenshots of the Google Form questions to develop the mobile application are also displayed.

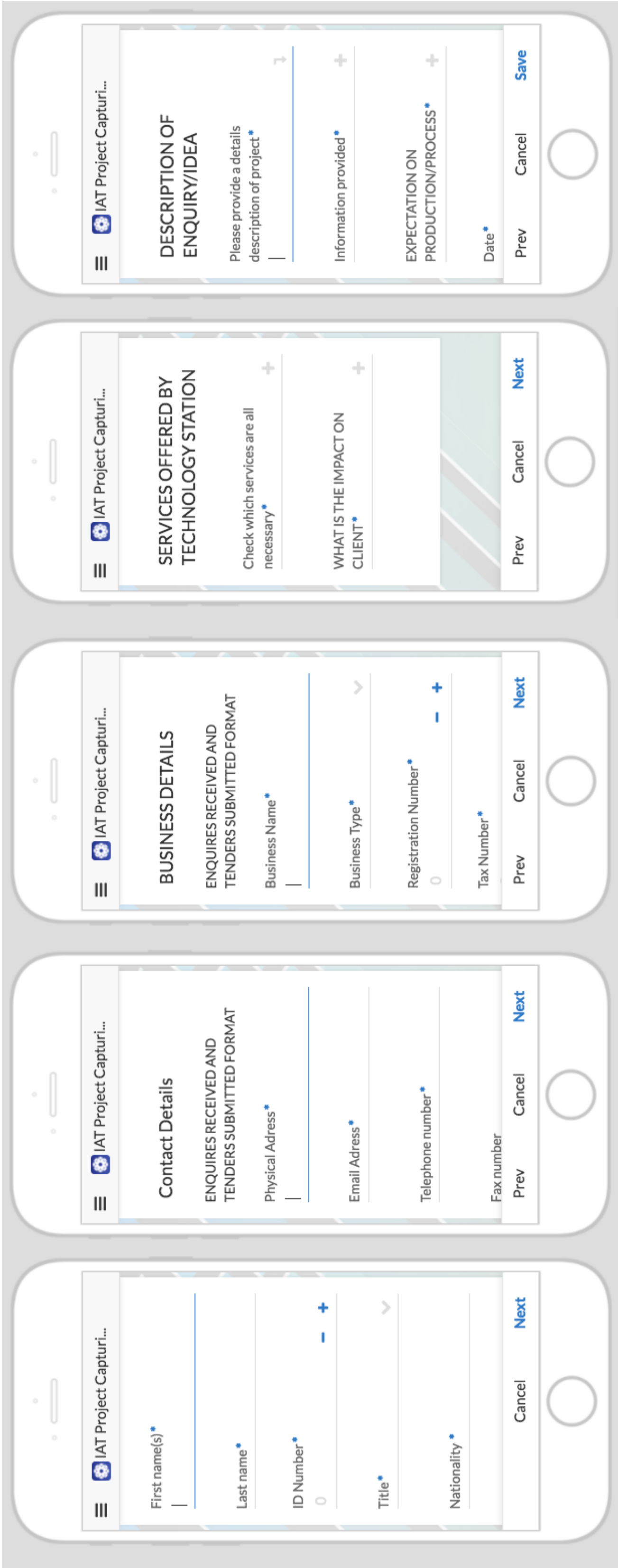


Figure 1: Mobile application developed with the use of AppSheet

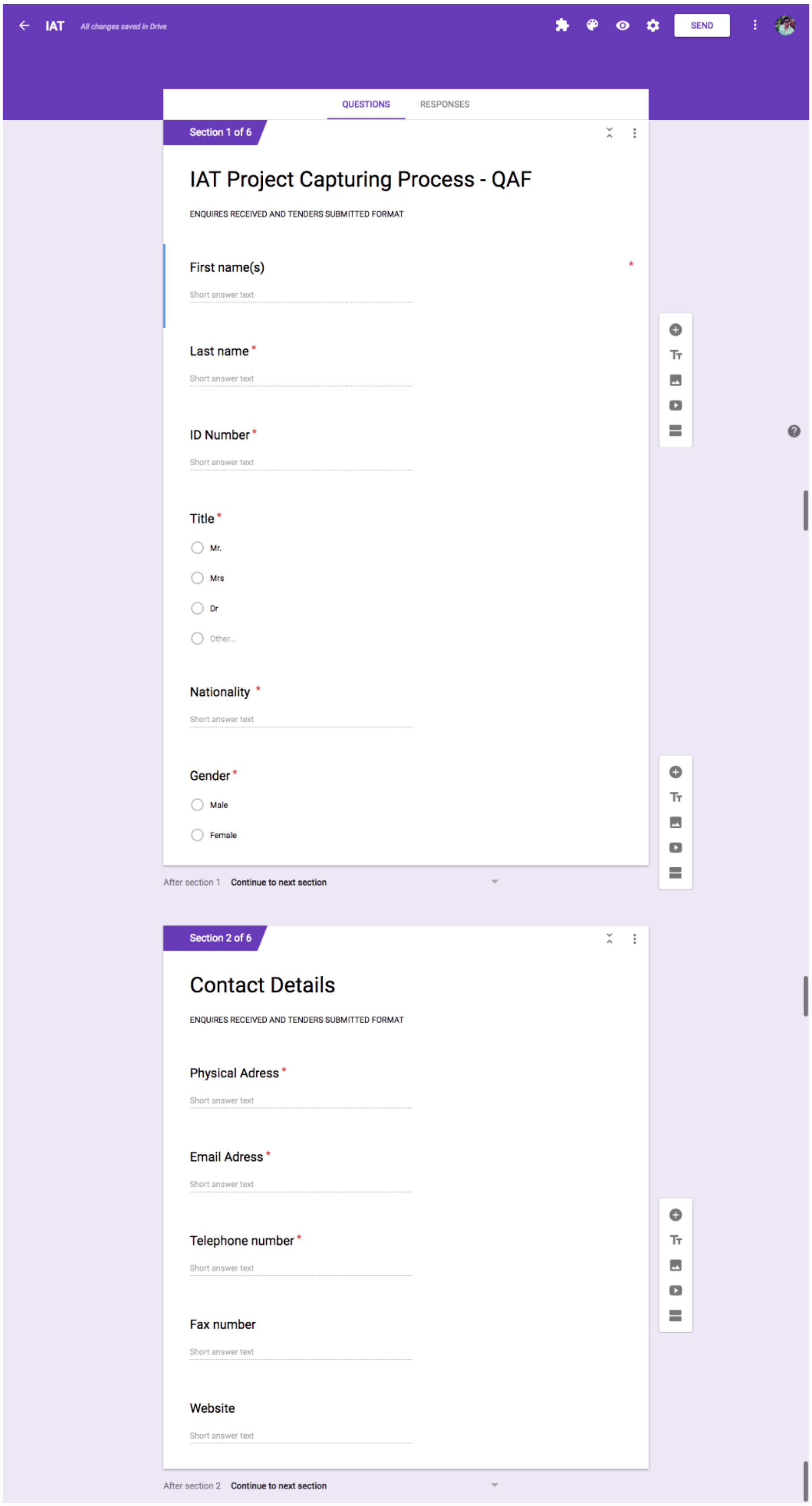


Figure 2: First screenshot of the Google Form replica of the IAT Client Capturing Form

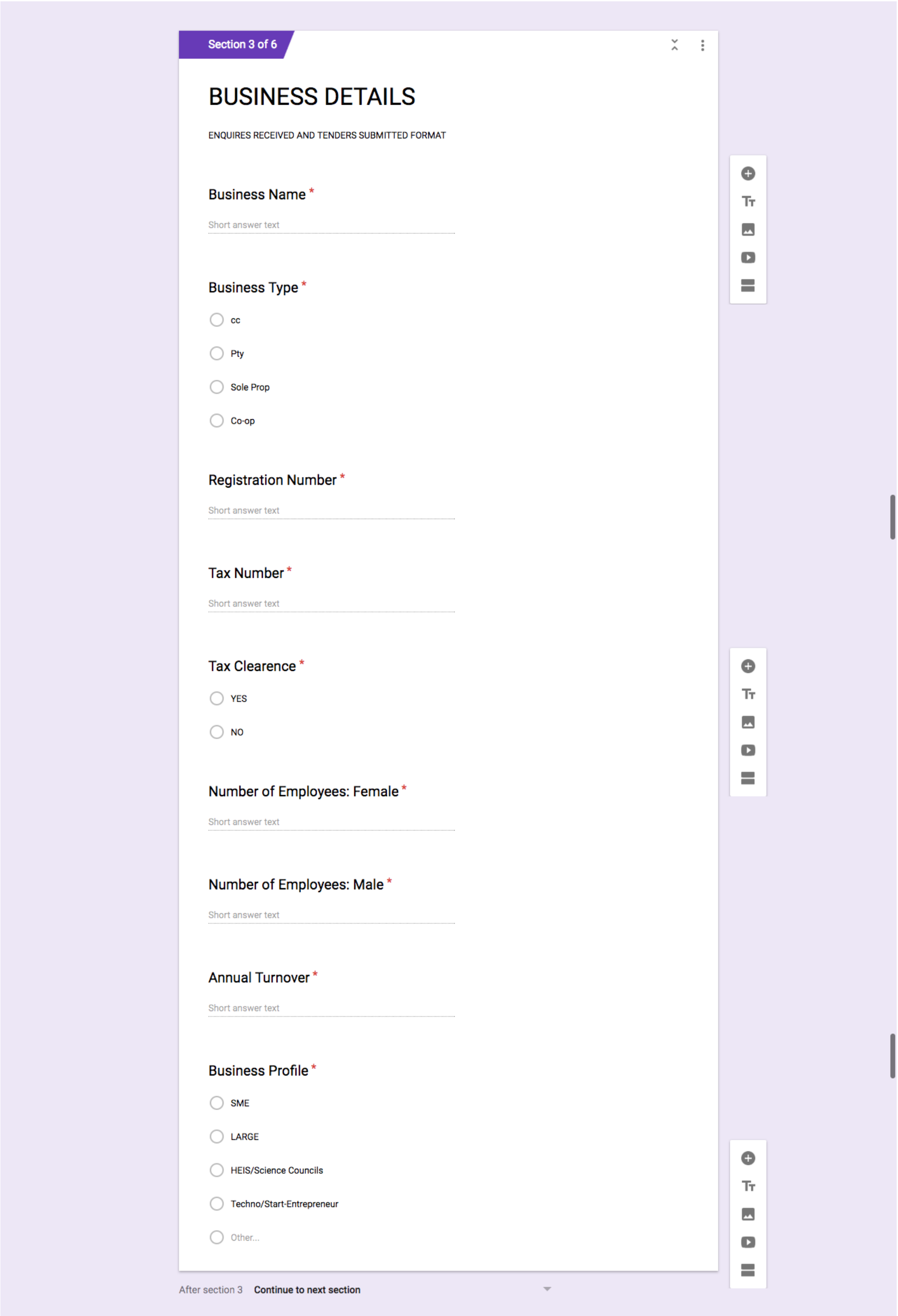


Figure 3: Second screenshot of the Google Form replica of the IAT Client Capturing Form

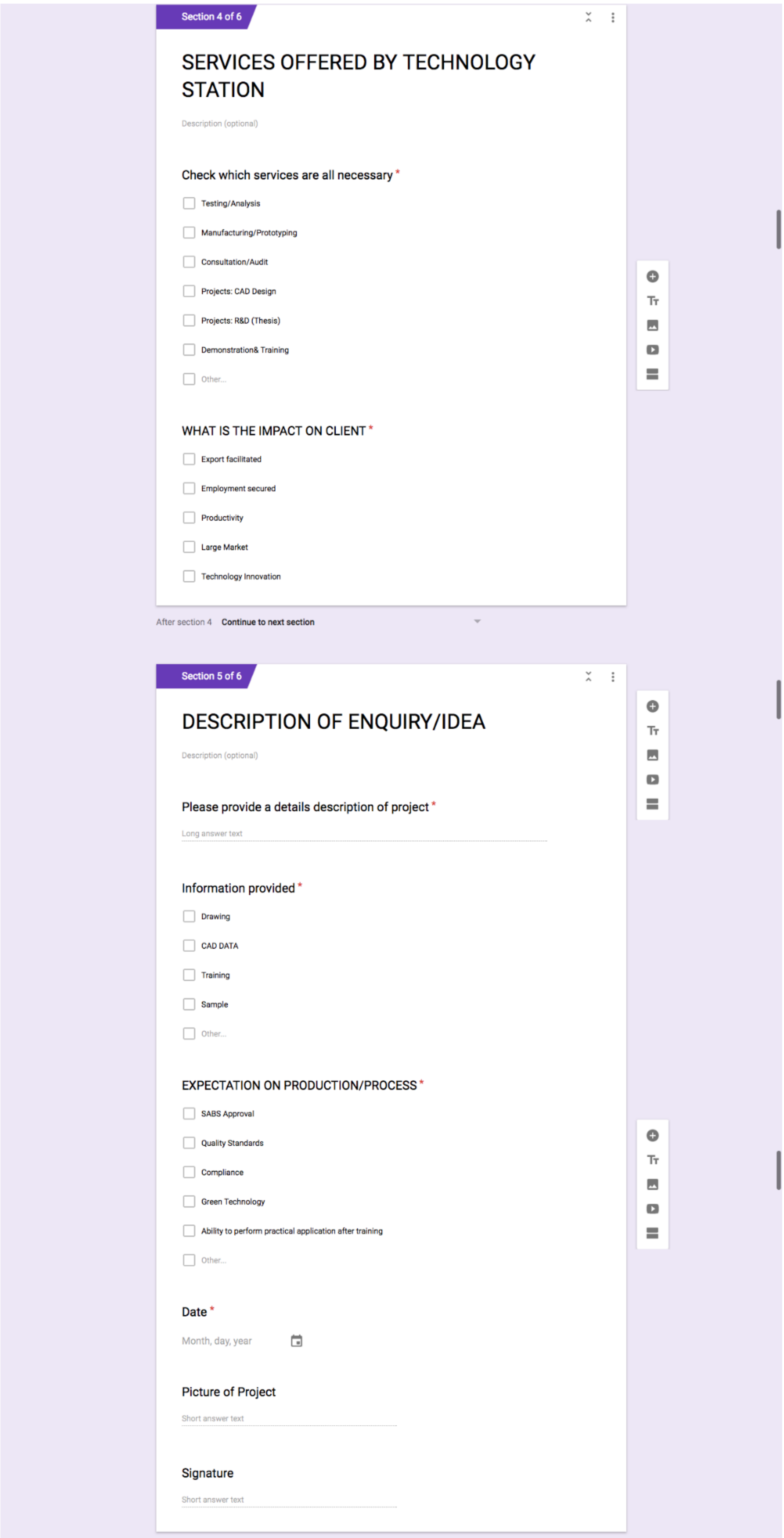


Figure 4: Last screenshot of the Google Form replica of the IAT Client Capturing Form

APPENDIX G: MOBILE APPLICATION RESEMBLING INVENTORY MANAGEMENT

This appendix displays the second mobile application that was developed to investigate resource management within the IAT and STC-LAM context. The mobile application is displayed together with the Google Form questionnaire that was created to capture the related information.

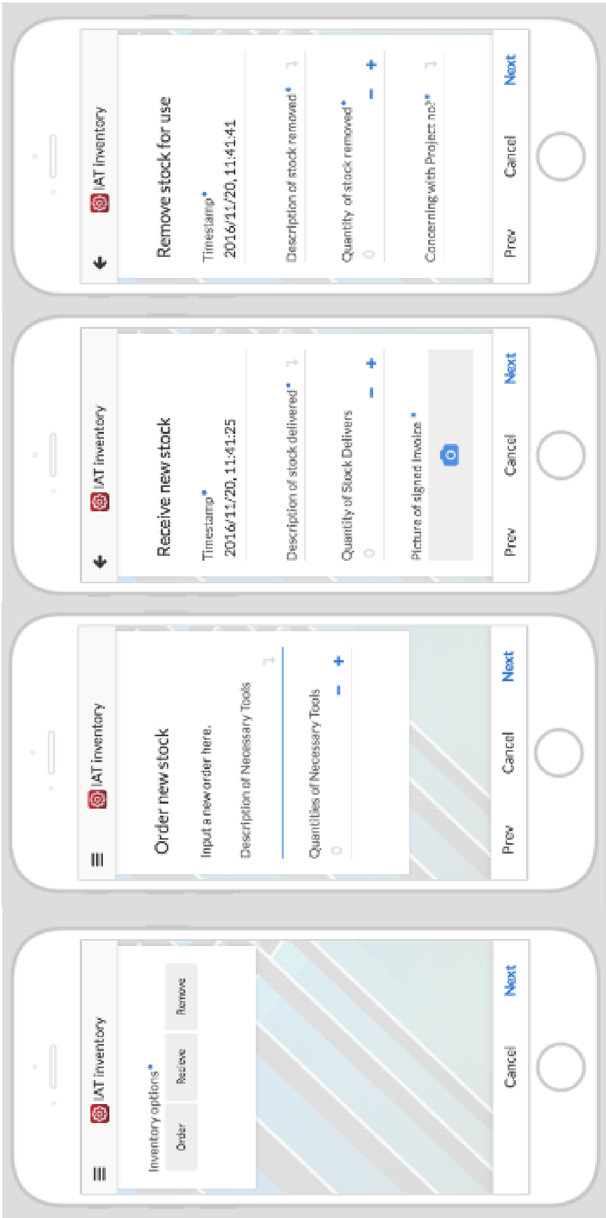


Figure 1: Mobile application to investigate resource management possibilities

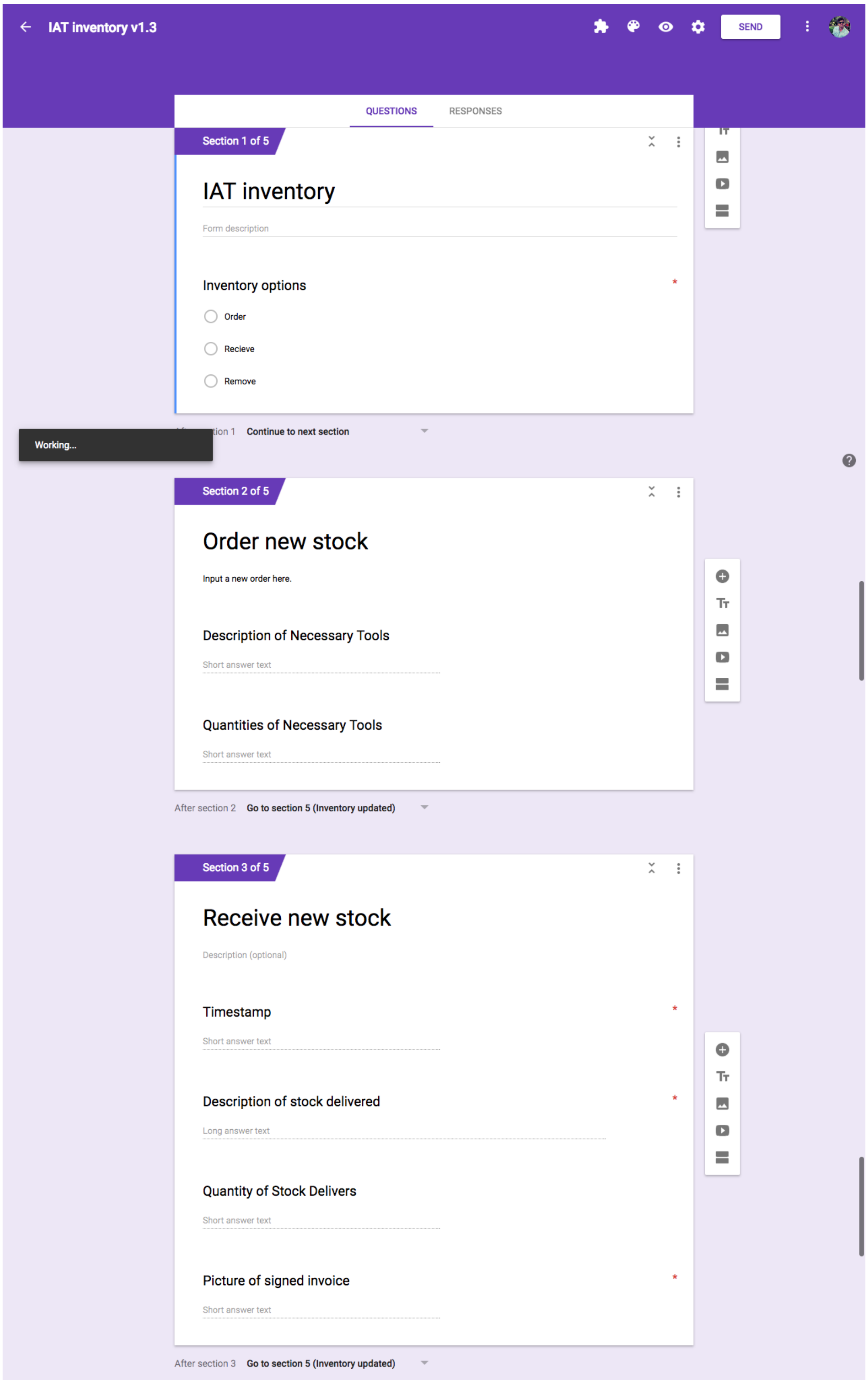


Figure 2: First screenshot of the Google Form replica used to create the mobile application

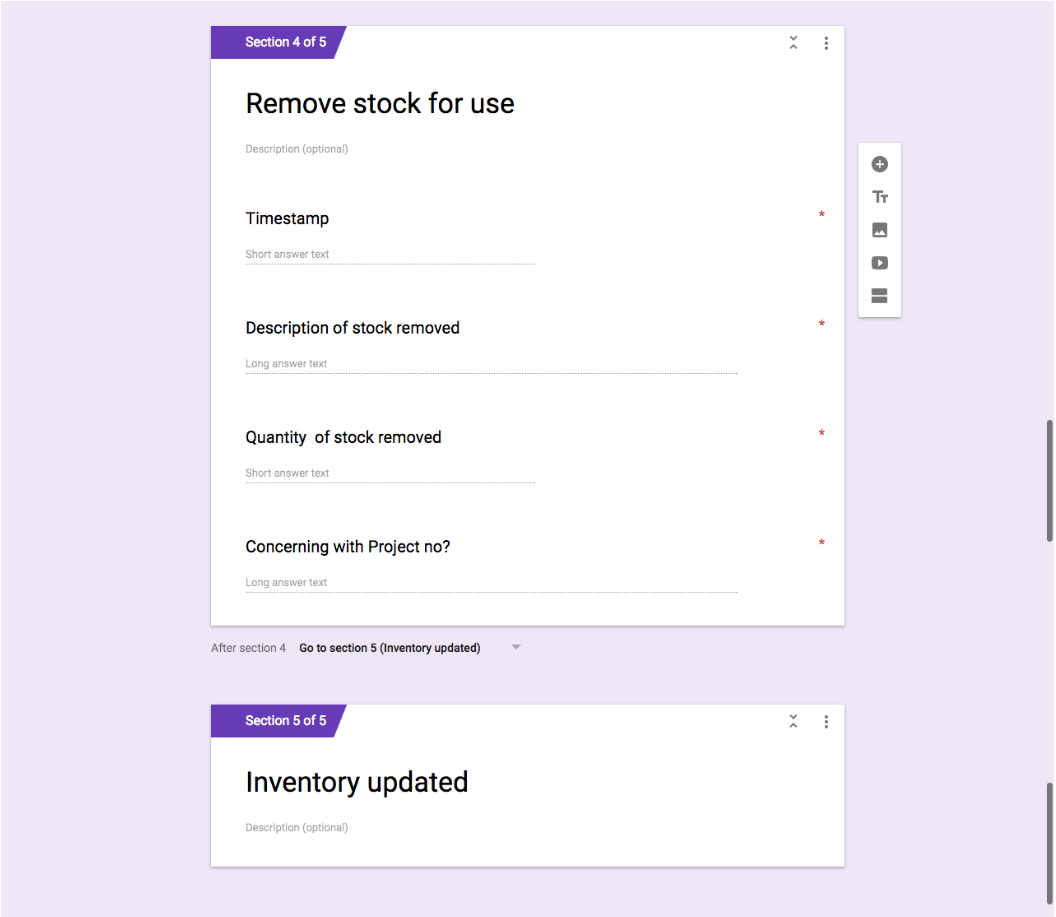


Figure 2: Second screenshot of the Google Form replica used to create the mobile application

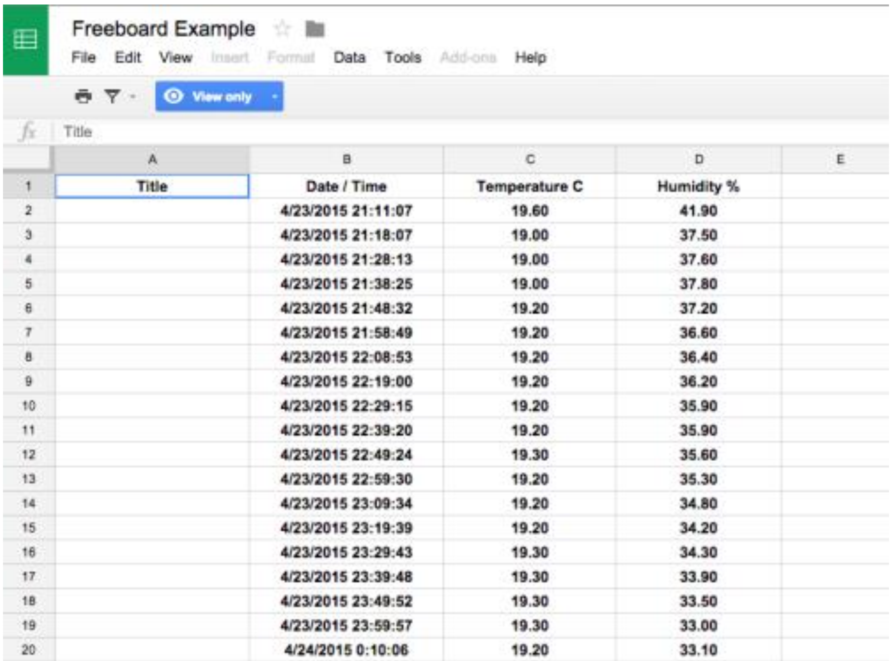
APPENDIX H: DASHBOARD CREATION TUTORIAL USING GOOGLE SHEETS AND FREEBOARD.IO

In this appendix, the dashboard that was created with on Freeboard.io is displayed and the process of displaying Google Sheet data on it is discussed.

Figure 1: Screenshot of the Freeboard.io dashboard that coincides with the resource management mobile application

Freeboard data storage with Google Sheets v1.3

In this tutorial, the use of IoT data collected on a Google sheet can be displayed on a Freeboard.io dashboard after these few steps. First populate the sheet with your data, similar to the example as shown below in Figure 2, then click on File and then Publish to the web on the dropdown menu.



	A	B	C	D	E
1	Title	Date / Time	Temperature C	Humidity %	
2		4/23/2015 21:11:07	19.60	41.90	
3		4/23/2015 21:18:07	19.00	37.50	
4		4/23/2015 21:28:13	19.00	37.60	
5		4/23/2015 21:38:25	19.00	37.80	
6		4/23/2015 21:48:32	19.20	37.20	
7		4/23/2015 21:58:49	19.20	36.60	
8		4/23/2015 22:08:53	19.20	36.40	
9		4/23/2015 22:19:00	19.20	36.20	
10		4/23/2015 22:29:15	19.20	35.90	
11		4/23/2015 22:39:20	19.20	35.90	
12		4/23/2015 22:49:24	19.30	35.60	
13		4/23/2015 22:59:30	19.20	35.30	
14		4/23/2015 23:09:34	19.20	34.80	
15		4/23/2015 23:19:39	19.20	34.20	
16		4/23/2015 23:29:43	19.30	34.30	
17		4/23/2015 23:39:48	19.30	33.90	
18		4/23/2015 23:49:52	19.30	33.50	
19		4/23/2015 23:59:57	19.30	33.00	
20		4/24/2015 0:10:06	19.20	33.10	

Figure 2: Example of data captured on Google Sheets

Next, duplicate the freeboard, seen in Figure 3 and found at: https://freeboard.io/board/J7ZTdZ

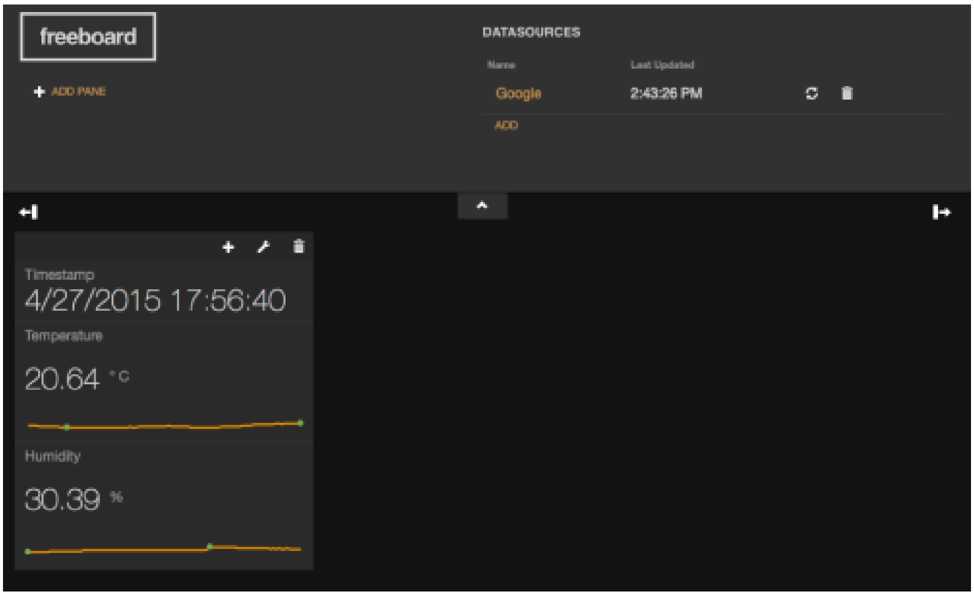


Figure 3: Dashboard duplication

Click the Google data source in the header, and change the Sheet Key to your particular Sheet as shown in Figure 4.

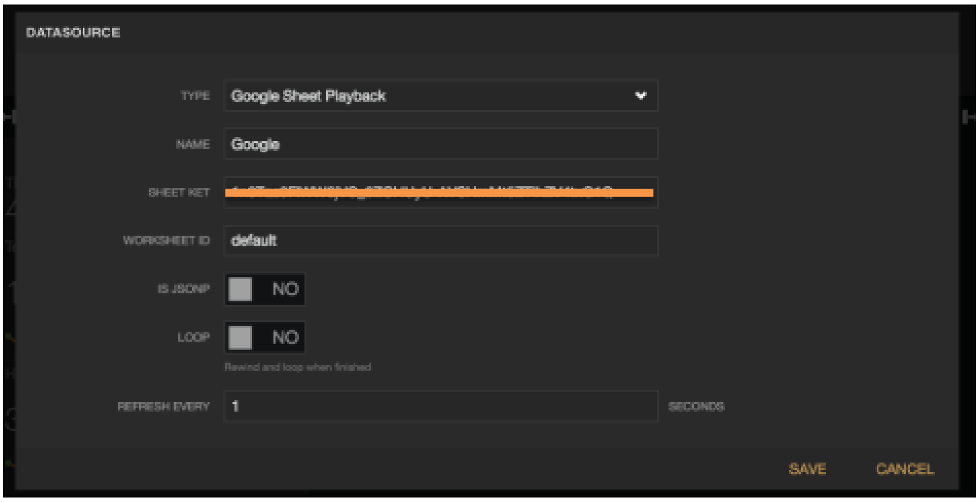


Figure 4: Updating of the Sheet Key in Freeboard.io

Note: The "Sheet Key" will be found in the Google Sheet URL of your published Google Sheet. For the example board, the key is in bold:

https://docs.google.com/spreadsheets/d/**1r6JYCFTu8z89_lWt8g6Kq7bEO1nkcCWKYNmT-F2vMlo**/pubhtml

Lastly, click SAVE, and your data will show up on your dashboard after a new display method is chosen and a Google Sheet column is assigned to it.