AN INVESTIGATION INTO THE INTEGRATION OF INDUSTRY 4.0 WITH LEAN MANAGEMENT IN SUPPLY CHAIN TO ADVANCE PRODUCTIVITY

by

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26 October 2022

"Inkanku idla amacimbi ngokwandulelisa"

IsiZulu Proverb

DECLARATION

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DEDICATION

I dedicate this research work to my late grandmother Sazile Buthelezi-Biyela who played an instrumental role in my upbringing and instilling values of hardworking, prayer and respect. I also dedicate this to my late parents Mrs Thuleleni Goodness Buthelezi-Mncwango and Mr Ndikiva Mncwango.

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ABSTRACT

This study investigated the implementation techniques that an organisation can follow to advance supply chain process efficiency by integrating lean management and Industry 4.0 initiatives in its procurement process for research equipment. The study reviewed models of integration for both Industry 4.0 and lean management approaches and suggests a seamless, integrative approach that can be implemented by organisations in a practical manner.

The higher education sector spends a substantial percentage on purchases of research equipment and related services annually, and then face multiple challenges regarding supply chain processes such as deficiencies in implementation of internal controls relating to supply chain management and procurement. These inefficiencies affect major research activities by having long lead times for research equipment and thus delaying the research process.

A survey was conducted to evaluate the efficiency of a procurement process for research equipment among the users of this process. It was found that there were various issues and inefficiencies in the procurement process and ERP system such team responsiveness, order accuracy, time taken to prepare and approve requisition and asset registration time. Moreover, a review of literature from practical cases where lean management and Industry 4.0 were implemented in supply chain processes was done to provide grounded practical recommendations.

The study proposes solutions from lean management and Industry 4.0 to improve supply chain efficiency for the procurement process and develops key performance indicators for tracking of performance and efficiency. The recommendations are grounded on digitalization enablers and lean management, with an integrative approach.

The study further makes a contribution by proving a blueprint that can be followed by an organisation to investigate supply process efficiency, identify areas of improvement, propose solutions, provide an implementation plan, and provide tracking mechanism.

The novelty of this research is that it proposes a practical approach of integrating industry 4.0 and lean management, not only from the point of theoretical framework but real-world application.

In summary, this study investigates supply chain efficiencies, tests the implementation of integration models for Industry 4.0 and lean management, and develop recommendations aimed at improving the supply chain efficiency, in a practical manner.

KEY TERMS

Title of thesis:

AN INVESTIGATION INTO THE INTEGRATION OF INDUSTRY 4.0 WITH LEAN MANAGEMENT IN SUPPLY CHAIN TO ADVANCE PRODUCTIVITY

KEY TERMS:

Industry 4.0, Internet of Things, Procurement, Supply Chain Processes, Lean management, Optimization, Lean Supply Chain, Robotic Process Analysis, DMAIC, Integration models, ERP Systems, Vertical Integration, Horizontal Integration, End-to-End integration

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LIST OF ACRONYMS

SCM	Supply Chain Management
RSC	Revenue Sharing Contract
LQDC	Linear Quantity Discount Contract
SCOR	Supply Chain Operations Reference
SCC	Supply Chain Council
4IR	4th Industrial Revolution
APICS	Association for Supply Chain Management
KPI	Key Performance Indicators
TPS	Toyota Production System
NCE	Nestle Continuous Excellence
SME	Small Medium Enterprises
RFID	Radio Frequency Identification
VSM	Value Stream Mapping
HEI	Higher Education Institution
IoT	Internet of Things
AI	Artificial Intelligence
AR	Augmented Reality
VR	Virtual Reality
MOOCs	Massive Open Online Courses
ERP	Enterprise Resource Planning
EIS	Enterprise Information System
SPSS	Statistical Package for the Social Sciences
ITSS	Information Technology Solutions and Services

DMAIC	Define-Measure-Analyse-Improve-Control
SMED	Single Minute Exchange of Dies
SIPOC	Supplier Input Process Output Customer
B2B	Business to Business
CC	Cloud Computing
N-DEMATEL	Neutrosophic Decision Making Trial and Evaluation Laboratory
AHP	Analytic Hierarchy Process
BOPS	Buy Online and Pick Up In Store
RPA	Robotic Process Automation
RASCI	Responsible-Accountable-Supporting-Consulted-Informed
3D	Three-dimensional
CPS	Cyber-Physical Systems
AIT	Accounting and Informatics
AS	Applied Sciences
AD	Arts and Design
EBE	Engineering and Built Environment
HS	Health Sciences
MS	Management Sciences
RIE	Research Innovation and Engagement

1. CHAPTER ONE: INTRODUCTION TO THE STUDY

1.1. Overview

The South African higher education sector spends a significant percentage on purchases of goods and services annually. The report by Statistics South Africa [1] stated that the total spend on purchasing of good and services by higher education sector contributed to 32, 28 and 26% (of the total receipts) in 2016, 2017 and 2018 respectively. This excludes capitalized goods and services by the 26 universities and university of technologies in South Africa.

The higher education sector is experiencing multiple challenges with regards to its supply chain processes. These challenges include lack of standardized processes and procedures which impacts efficiency [2].

Other challenges include lack of performance monitoring and management systems as well as lack of adherence to the principles of demand and acquisition management within the broader University – supply chain management often used as a “buying department” [2]. These challenges are further affirmed by Dlamini [3], in a study that determined the challenges faced by comprehensive universities in South Africa hindering the implementation of best practices. These challenges include

- manual systems delays and technology inefficiency
- unethical conduct
- capacity and shortage of skilled staff

The issues relating to capacity and shortage of skilled staff stems from, among others, the gap between what employers need and what training institutions for supply chain practitioners deliver [4]. The study by Bennis and O’Toole: [5] states that there is an imbalance between the trade training and theoretical training, with most time spent on theoretical training in business schools. This contributes to the improper skilling of the practitioners. In another study by Jordan and Bak [6], further affirmed that training institutions for supply chain practitioners had a limited emphasis on information technology skills, notwithstanding the substantial IT progressions and changes in supply chains.

The last cause of the skills and capacity challenge is about connecting the existing gap between academia and industry. While there is an inclination to include industry perspective in developing Supply Chain Management prospectus, there is little involvement of industry the formulation of the curriculum [7]. According to Lutz and Birou, [7]: “There was no inclusion of an industry perspective in determining what should be taught in these classes, just a list of what academics think should be taught. This leaves a gap that may cause students to be unprepared as they leave the classroom.”

At the DHET level, one of the causes of the lack of standardized processes is that universities are not obliged to comply with the requirements of the Public Finance Management Act [8]. This allows universities to develop their own standard procurement processes with may be inefficient, thus creating a comparison point between universities. In contrast, this may not be a bad practice as it allows each university to develop processes that are defined by the procurement landscape and challenges specific to each operating environment. Within the South African context, some university councils have decided to adopt the principles of the act, as it results in effective management of finance and supply chain management [2].

The lack of performance monitoring is as a result of departments instructing the buyer to use their preferred supplier because it is the only supplier who gives that particular service and this affects in proper monitoring of supplier performance [2]. The other causes of the challenges in the front of performance monitoring include the emergency orders that can encourage irregular expenditure.

In this project, the current procurement processes are constituted by hybrid processes of manual processes and Enterprise Resource Planning systems which are not extremely outdated and cannot handle major modern tasks that an ERP must perform. This is one of the causes of the challenges in the manual systems and technology. The inefficiencies in university supply chains processes such as procurement, affect major research activities by having long lead times for research equipment, software, and other enabling tools. Supply chain processes are the heartbeat organisations to ensure production and proficient service provision. For any sector, efficient business processes are critical and imperative. On the organisational level, for the realization of business targets, a special attention to supply chain is essential, as this is the hub of the company activity. In order to remain competitive, the higher education sector needs to continuously improve its supply chain processes, as they are key to optimal performance.

The first industrial revolution was in the 18th century and steered organisations from manual to mechanization industrial processes [9]. In the 19th century, new mass production methods led to the 2nd industrial revolution [10]. The innovation of technology from analogue electronic and mechanical devices to digital technology characterizes the third revolution which began during the 1970's [11].

At present, the world is focused on 4th Industrial Revolution (4IR), which is characterized by connectivity of technologies built during the digital revolution [11]. This blurs the lines between the physical, digital and biological entities [12]. Coined at Hannover Industrial Fair in 2011, Industry 4.0 originated with the intention to raise the level of German manufacturing through the connectivity of old and new technologies [13]. According to Baines et al, [9], this era will radically change the human use of technology, with major implications for the ways people live and work.

Project initiatives from Industry 4.0 are being implemented while there are existing business improvement approaches. There is a need to do more research on this area of lean management and Industry 4.0 as to provide ways for universities to implement both these initiatives without interrupting the supply chain objectives and focusing on the efficiencies needed. There has been a vast attentiveness in government and private sector approach in 4IR. However, there are existing management approaches in organisations. Therefore, this research is important for the identification of synergies in implementing both Industry 4.0 and lean management as to avoid contrasting actions.

The project will propose solutions that a higher education institution can implement lean management to improve supply chain efficiency. Furthermore, the research proposes solutions that are linked to Industry 4.0, in order to advance efficiency in supply chain processes in the higher education sector. These processes range from the procurement of research equipment, consumables, hardware and software. The equipment ranges from specialized computers, laboratory equipment and research service and contribute a big percentage of the total operating costs of a university and thus a need focus on efficiency. Lean management has been an important catalyst in order to improve supply chain departments' key performance indicators, as well as value creation for the whole organisation.

1.2. Problem Statement

The higher education sector is experiencing multiple challenges with regards to its supply chain processes. These challenges include lack of standardized processes and longer lead times which impacts efficiency [2]. For example, the Durban University of Technology, noted that there were deficiencies in implementation of internal controls relating to supply chain management and procurement [14].

These inefficiencies in university supply chains such as procurement processes are affecting major research activities especially with the delay of procurement for research equipment.

Lean management has been used successfully to improve efficiency in supply chain processes. With the progression and implementation of Industry 4.0, there is an increase in digitalization actions to focus on greater business results and productivity. Major organisations are focusing on implementing Industry 4.0 initiatives in supply chain processes to advance efficiency and productivity. At the same time, there is currently some pockets of application of Industry 4.0 in the institution, with no coordination.

It is uncertain whether this implementation is in line with existing continuous improvement techniques such as lean management, which is known to have benefits in advancing business objectives. Therefore, this research is important in further exploring the synergies and practical implementation of both Industry 4.0 and lean management in order to improve supply chain efficiency of a university procurement process, and to avoid contrasting actions in implementing lean management and Industry 4.0 initiatives for this process.

1.3. Purpose of the Study

1.3.1. Aim of research

The main aim of this study is to investigate the current supply chain process efficiency at an institution of higher learning and propose solutions that advance productivity using an integrative approach that encompasses Industry 4.0 and lean management.

These recommendations are grounded on integration models of lean management and industry 4.0, as well as practical application of theoretical constructs in both management approaches. The study, then, seeks to make a contribution by proving a blueprint that can be followed by an organisation to investigate supply process efficiency, identify areas of improvement, propose solutions, provide an implementation plan, and provide tracking mechanism.

1.3.2. Objectives

The objectives of the research study are to:

- Investigate current practices and efficiencies in the procurement process for research equipment at an institution of higher learning.
- Review models for integration of both management approaches in order to suggest a seamless integrative approach that can be implemented by organisations.
- Research case studies where lean management and industry 4.0 have been implemented, with a view to develop grounded model solutions to address inefficiencies in the procurement process being studied.
- Propose solutions grounded from lean management and Industry 4.0 to improve supply chain efficiency for the research procurement process.

1.3.3. Research Questions

The main research question is: How can an institution of higher learning implement Industry 4.0 and lean management through an integrated approach in order to advance supply chain process efficiency procurement process for research equipment? There are four sub-questions, namely:

- What are the current practices and efficiencies in the procurement process for research equipment at an institution of higher learning?
- What are the integration models that can be used to implement Industry 4.0 and lean management for an integrated continuous improvement approach?
- How can lean management and industry 4.0 initiatives be implemented in an integrated manner in order to advance supply chain efficiency?
- What are the solutions from lean management and Industry 4.0 that can be recommended to improve supply chain efficiency for the procurement process?

1.3.4. Significance of the Study

Efficient supply chain processes are critical components of a successful company, more importantly so, in a university, where diverse items are utilized daily. A typical supply chain includes planning, procurement, warehousing, distribution, production, customer services departments.

Buys, [15] reviewed the South African government's plans to increase the student enrolment in the higher education sector to approximately 1.62 million by 2030. From that, expenditure levels will increase, and procurement of research laboratory equipment, everyday consumables, and software and journal subscriptions will have to be managed efficiently. This means that procurement of resources via supply chain management (SCM) processes will become progressively crucial in ensuring that higher education institutions achieve the ambitious target. The efficiency advancement techniques (management approaches) to achieve efficient SCM, should be implemented efficiently for government targets to be met at economical expenditure. These management approaches include lean management and Industry 4.0 initiatives.

Project initiatives from Industry 4.0 are being implemented while there are existing business improvement approaches. There is a need to do more research on this area of lean management and Industry 4.0 as to provide ways that organisations can implement both these initiatives without interrupting the supply chain business objectives. The integration models described in the literature review need to be reconnoitred further and practical implementation is essential to evaluate practicality and develop additional models of integration.

1.4. Research Methodology

Research philosophy, according to Bajpai [101], is the belief by the research community of the right ways pertaining to data collection of a phenomenon and how it should be analysed and used. This study follows a positivist approach because methods applied in the positivist approach separates the researcher from the study procedure; hence the views and beliefs of the researcher would not influence the end results of the study [16]. The other reason for choosing this research philosophy is that it adheres to both factual and measurable data, which assists in considering that the research undertaken is an observable and measurable phenomenon of one aspect against the other.

The mixed method approach was used as it combines both the qualitative and quantitative approaches. The research used the mixed method approach following the advantages it brings to a research study and the embedded nature of the research itself. The data collection method employed in this study is a survey questionnaire. The research methodology used in this study is explained in detail in Chapter 4.

1.5. Population

The population for the survey is all departmental administrators (staff), postdoctoral researchers and fulltime second year doctoral students involved in buying research equipment or services. This population was chosen because it utilizes the procurement process in the university. The student compliment of 2nd year students is chosen because, in normal circumstances, finish their research proposal in the 1st year, then on the second year they collect data and that is when they may get involved in the procurement of research equipment. During their 3rd year, the students normally wrap-up their studies and therefore not included in the study. Typical case purposive sampling was used as the research study focused on a typical problem faced by a researcher when purchasing research equipment.

1.6. Limitations

The study considers lean management application to advance productivity in supply chain processes. These processes are within the context of higher education sector i.e., university procurement process. The procurement process for research equipment differs slightly from the other general items and this study will only study this process. The integration of lean management and Industry 4.0 initiatives within the higher education sector will be limited to the three-theoretical models (vertical integration with lean management, horizontal integration plus lean management as well as end-to-end engineering integration and lean management). The research was limited to the administration staff, 2nd year fulltime doctoral students and postdoctoral fellows who are the potential users of the university procurement process for research equipment. This study does not cover the Public Financial Management Act as the university forms part of the unlisted public entities as per the PFMA Act [8]. While the study focuses on industry 4.0, it is worth noting that Industry 4.0 in South Africa is still in its infancy.

1.7. Thesis Structure

The thesis is structured into 8 Chapters.

CHAPTER ONE: INTRODUCTION TO THE STUDY

This chapter covers background information, statement of the problem, research objectives, research questions, definitions, and limitations.

CHAPTER TWO: PROCESS ARCHITECTURE

This chapter lays out the structure of the university and the procurement process used in the study.

CHAPTER THREE: LITERATURE REVIEW

This chapter includes a theoretical basis for the study, grounded in a comprehensive literature review.

CHAPTER FOUR: RESEARCH METHODOLOGY

This chapter presents the research methods and the research constructs.

CHAPTER FIVE: CONCEPTUAL FRAMEWORK

This chapter lays out the conceptual framework and theories used in the study.

CHAPTER SIX: SURVEY RESULTS AND CASE STUDIES' REVIEW

This chapter presents the results of the data analysis.

CHAPTER SEVEN: RECOMMENDATIONS

This chapter focuses on the recommendations that address the inefficiencies and issues identified in the results.

CHAPTER EIGHT: CONCLUSION

This chapter consists of the summary of research study, significance and the contribution to the body of knowledge, as well as future research work.

1.8. Chapter Summary

There is a wide range of literature into implementation of lean management to advance productivity in organisations. When implemented to improve supply chain processes, lean has delivered good results and major improvement. Therefore, in this study, it will be utilized to improve efficiency of supply chain in higher education sector, which is critical in a country's development. Concurrently there is a movement of Industry 4.0 with major implications on the future of higher education sector. There is an exciting need to understand the integration of Industry 4.0 and lean management approaches for synergetic implementation to improve supply chain efficiency.

2. CHAPTER TWO: PROCESS ARCHITECTURE

2.1. Location of DUT within the Higher Education Landscape

The Durban University of Technology forms part of South Africa's 26 public universities. These universities are part of the Department of Higher Education and Training (DHET). The DHET also encompasses the Technical and Vocational Education and Training (TVET), which is responsible for dealing with TVET Colleges [17].

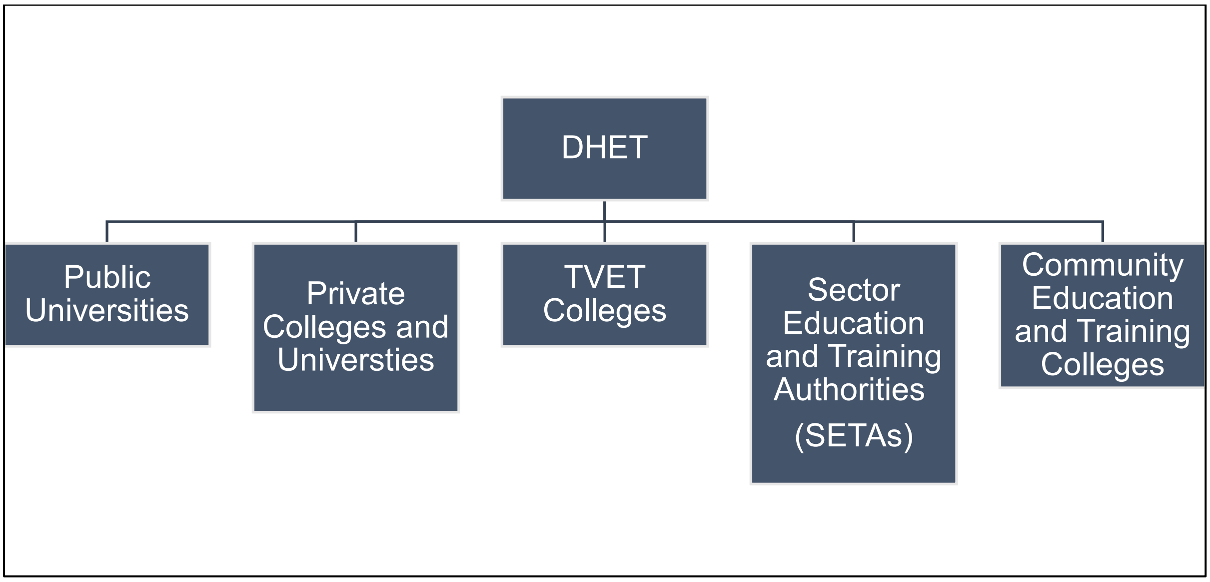


Figure 1: Overall Structure of Higher Education Institutions in South Africa

The DUT is part of the Universities South Africa (USAf), which is an umbrella organisation comprising of 26 public universities distributed in all nine provinces in South Africa. The Vice-Chancellors or principals of the all member universities, who act as accounting officers of their respective universities, constitute the Board of Directors for this body [18]. The Board leads and contribute to Strategy Groups which give effect to Universities South Africa's strategic framework by shaping, conceptualising, and directing the implementation of projects and programmes.

2.2. Organisational Structure

The organogram for the institution is critical in identifying responsibilities and roles within an organisation. This is acknowledged by DeCanio et al. [19] by stating that the organisational organogram impacts general behaviour of the employees, value chain, units and subunits with the organisation. For this study, it is important to understand the organogram as to identify the roles of levels of management in the requisition approval architecture. This clearly identifies the approval and delegation authority impacting on the procurement process for research equipment. The Executive Management Committee is responsible for the management of the institution and has the approval authority. This is an abridged organogram to highlight the procurement approval hierarchy.

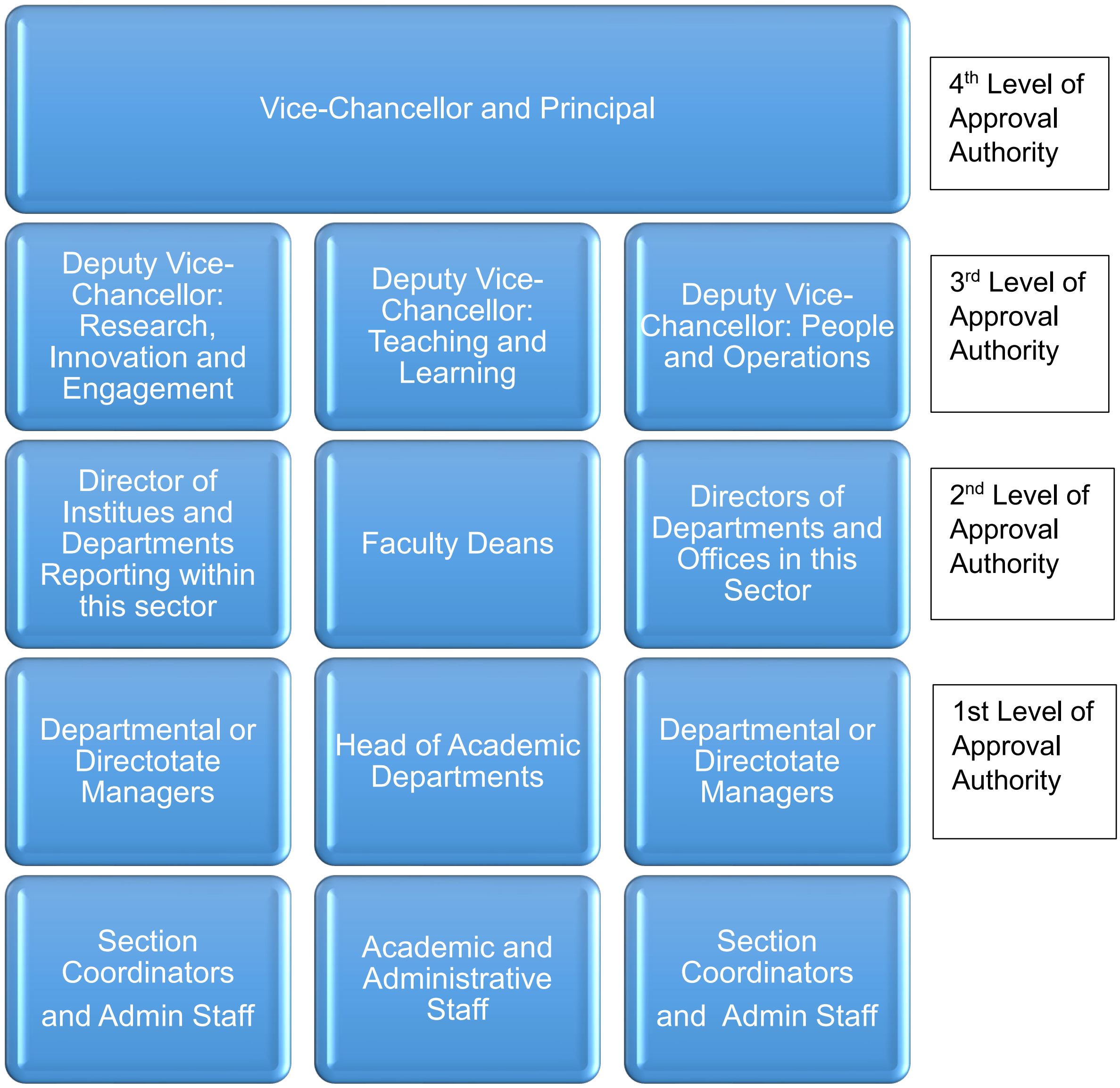


Figure 2: Organogram and delegation authority

Source:[20]

2.3. Current Procurement Process Considerations

2.3.1. Manual Process

In this process, it is mandatory that all requisitions are signed off by the originator and 1st level of approval authority. If the requisition is originated by the person responsible for 1st level of approval authority, they cannot sign as both originator and approver. The next level of authority becomes the first level approval and so on.

- all requisitions are signed off by the originator and the approver.
- requisitions below R1 000, one written quotation is required.
- all requisitions above R1 000 the following must have three quotations, summary of quotation form.
- for sole suppliers, the solitary supplier letter must be attached to the requisition.

2.3.2. Electronic Requisitions

This electronic channel must be used all requisitions below R10 000, where the supplier is on the database must be processed using the ERP system and all documentation and approvals must be filed by the department for audit purposes.

2.4. Procurement Delegation of Authority

The approval of purchase requisitions follows the approved process. This process is depicted below. It is multi-layered and clearly explains the amounts that can be approved at which power or authority.

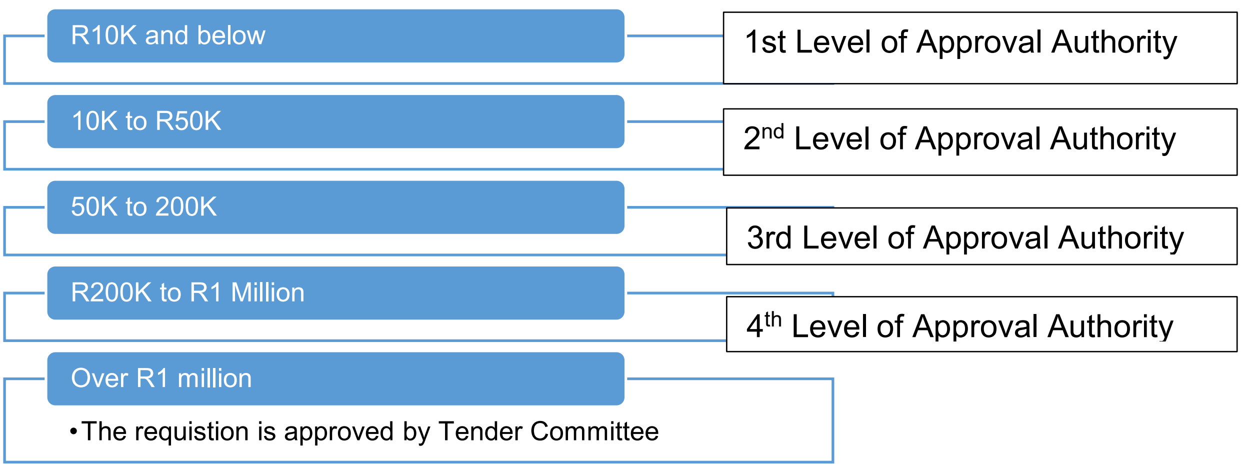


Figure 3: Delegation Authority for different amounts

2.5. High Level Process Flow for Item Values

There is a set procedure for each requisition type explained above. The figure below condenses the requisition process followed for each process type.

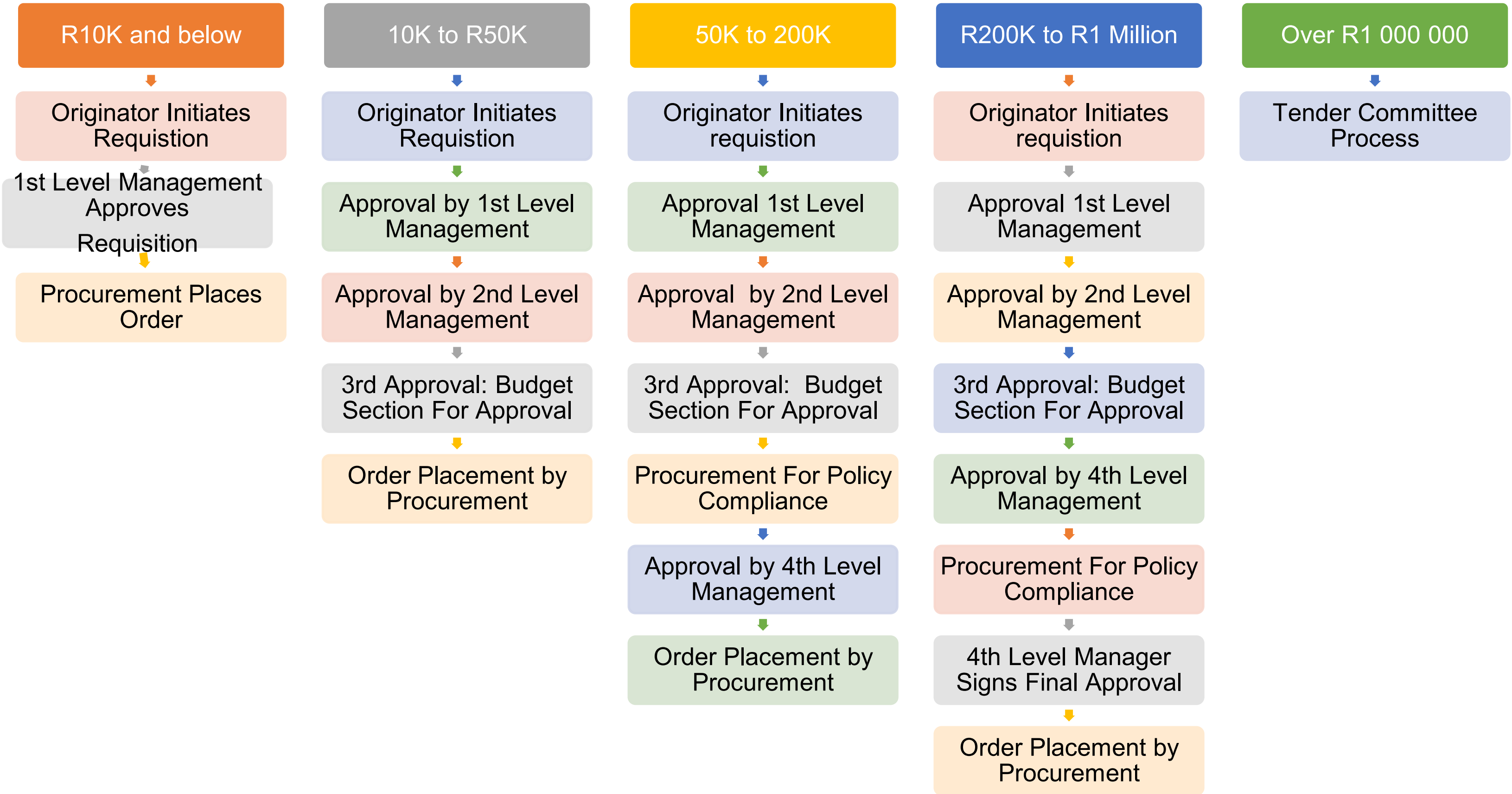


Figure 4: Process Flow for each requisition value limits.

2.6. Operational Process for Research Equipment Procurement

Steps	Process Diagram
0	**Start** ↓
1	**Prepare Requisition on the ERP System.** This can be using the creating the requisition online via ITSS System. The alternate method is manually using the requisition book. Another option is when the requisition is done manually but as soon as it reaches procurement, it will be captured on the ITSS and then follow the online process. ↓
2	**Requisition Approval.** The requisition is the approved by the approver as per the delegation of authority diagram in Figure 3 before being sent to ↓
3	**Oder Entry time on the system after approval.** After approval, then the procurement validates the requisition against the required documentation needed for each requisition type**.** ↓
4	**Budget Approval and coding.** This is to check if there are sufficient funds for in the cost centre. ↓
5	**Release of purchase order by procurement to the supplier using the pre-agreed terms in the service level agreement or memorandum of understanding.** ↓
6	**The supplier manufactures the equipment or** **The supplier prepares the service using the description in the Purchase Order.** ↓
7	**Delivery of equipment/product or service by the supplier** ↓
8	**Asset Registration by using the Purchase Order and Delivery Note** ↓
9	**Yes** is the equipment fit for use Or is service satisfactory**?** **No**
10	Institute Warranty Procedures or Service Agreement Proceedings ↓
11	Install equipment for use or process further (for services) ↓
12	End

Figure 5: Operational Process flow for the procurement process

2.7. Chapter Summary

This chapter starts looks at the location of the institution that is being studied, within the context of the higher education landscape in South Africa. The focus is on the organisational structure and the organogram. This is done in order to highlight the role of the structures in the procurement process of research equipment. The delegation authority responsible for approval is discussed and the amount limits for which they can approve. The process diagram depicting the flow of activities and tasks in the procurement process of research equipment is shown to further elaborate the operational requirements of this process. The emphasis on this is done as the research equipment is usually linked to the funding instrument linked to the external funding. Although the funding source may be external, the university financial policies and procedures are followed when purchasing the research equipment and services.

3. CHAPTER THREE: LITERATURE REVIEW

3.1. Supply Chain Overview

Historically, organisations put effort into making products and give a little thought to the ways these products were passed on to customers, and supply chain remained an abstract concept and logistics was not a term that was commonly used in business [21]. Distribution was an unavoidable cost of doing business and this really meant transport which required low skill levels [21].

The need for reducing the distribution costs was seen and this led to the definition and development of supply chain. Waters, [21] also defines supply chain as a complex network of connections and relationships among functional units at successive stages, both within the organisation and with outside suppliers, customers and service organisations.

A supply chain is a global network of organisations that cooperate to improve the flows of material and information between suppliers and customers at the lowest cost and the highest speed. The objective of a supply chain is customer satisfaction [22]. The authors use of the term "network" to suggest that the companies involved in a supply chain could not only be companies that perform complementary activities but also companies that compete to perform the same activities [22].

Prasetyanti & Simatupang, [23], also suggested that a supply chain consists of activities and facilities performed to fulfil customers’ requests. The role players involved include manufacturer, suppliers, transporters, warehouses, retailers, and customers. The authors further suggest that the recent focus on supply chains are value creation and value constellation for the customers.

A typical supply chain in an organisation has a set of activities directly linked by upstream and downstream flows of products, services, finances and information that collaboratively pull what is needed to meet the needs of the individual customer. An example of a supply chain would comprise of demand and supply planning, procurement, inbound transportation, warehousing, outbound transportation, customer services and customer collaborative planning [24].

Kain & Verma [25] makes an attempt to understand the importance of logistics by understanding the concepts of logistics and logistics management in supply chain and presenting a conceptual methodology. This methodology encompasses identification of various current logistics issue through direct observation in logistics industry, reviewing the literature for concepts theories and review previous research finding. This is followed by hypothesis formulation and data collection for execution. The last step in this methodology is data analysis to formulate report i.e., output of methodology. The shortcomings of this article are that it does not have an empirical validation of the proposed methodology.

Hugos [26] distinguishes between supply chain management and the traditional concept of logistics. The author further describes logistics as intracompany activities a single organisation and supply chains as networks of organisations coordinate works and actions to distribute a product to market.

A further distinguishing factor is that customary logistics is solely focused on activities such as procurement or purchasing, distribution of materials, maintenance of equipment, and inventory management. Supply chain management encompasses traditional logistics and does not leave behind activities such as marketing, demand forecasting, new business development, finance, and customer collaborative services, therefore being inter-organisational.

3.2. Process Supply Chains

Process supply chains can be described as interconnected sets of entities responsible for the sourcing, production and distribution of a large set of chemical and/or bio-based products [27]. In their paper, Lima et al. identified and discussed contributions, challenges and perspectives in process supply chains that can guide research professionals to address such challenges (industrial gas supply chain). In this article, the authors describe supply chain activities in the industrial gas sector. They include upstream, sourcing, production, storage and distribution [28].

Altiok and Melamed [29] define a supply chain system as a network that mediates flow within the entities involved in a product life cycle, from production to vending. In the supply chain network arena, this has nodes representing suppliers, manufacturers, distributers, warehouses, and inventory facilities.

In between the nodes, arcs act as connectors which goods are transported. The further observed that, supply chains consist of with upstream and downstream components. The material flow including raw materials, subcomponents, final products flowing downstream. Demand forecast information, payments, market insights flow upstream. Information flow is bidirectional.

The description by Syahrir et al. [30] further cements the importance of integration between operational management, information technology, inventory and control management, strategic management, and service management in the healthcare and disaster supply chains. The literature surveyed in this article has a consensus on the importance on integration of the main elements of a supply chain.

Through a systemic a systematic literature review, Mrabet et al. [31], considers that supply chain is a complex system or a system of systems. This is derived from acknowledgement of important contributions of earlier thinking to current work on defining supply chain. They then show that there are four categories of definitions as sets of entities, activities, processes and systems. This paper is comprehensive because it demonstrates a dynamic evolution supply chain all over a period of years.

In this paper, Zhao et al. [32] considered the supply chain coordination with a revenue sharing contract (RSC) and a linear quantity discount contract (LQDC) in a fashion supply chain with demand disruptions. The situation without demand disruptions is considered as the benchmark. In the benchmark, the RSC fails to coordinate the supply chain while the LQDC does. The author also found that demand disruptions can promote supply chain coordination and in some cases, the RSC (LQDC) coordination fails to synchronize the supply chain whereas the LQDC (RSC) synchronizes the supply chain.

Eksoz and Onka, [33] Revelled the importance of distribution in the customer collaborative supply chains for food distribution. They argue that the distributor is not given deserved attention as its supply plans are greatly influenced by the logistics (Intra Company) as well supply chain (intercompany) uncertainties. They stress the importance of building bridges that reduce demand volatility and influence target achievements across the value chain.

Sakhuja and Jain, [34], developed a conceptual method of a service supply chain which assists in visualizing the integrated service network. This work was based assessed on literature review on Service Supply Chains. They further highlighted the important research directions which can be a part of service supply chain. The shortcoming of this framework is that it is based on general theory and lacks the empirical real data for validation.

Figure 6: Supply Chain Value Streams

Source: [35]

The coordination is further demonstrated by the diagram developed below.

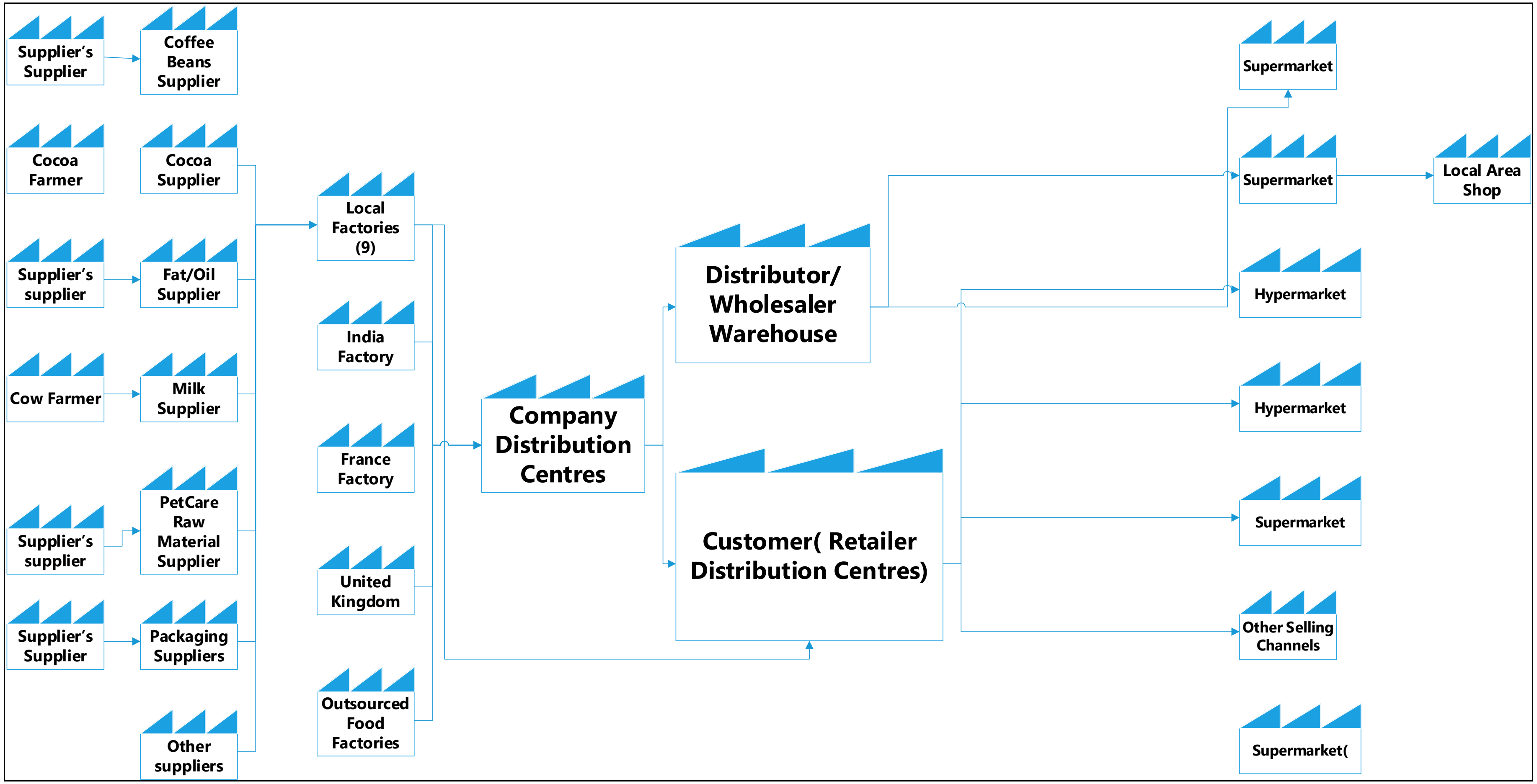


Figure 7: A typical material flow for a global FMCG company

Source: [35].

3.3. Procurement

The role of procurement in an organisation is beyond the customary belief that procurement's primary role is to purchase goods and services in response to organisational needs [36]. It supports operational requirements such by understanding business requirements, quantifying them and fulfilling them [36]. When fulfilling the demand for these products and services, the important considerations are right source, price, quantity, specification and more importantly at the right time for use.

Public procurement is one of the major economic activities in the world and accounts to 12% of GDP for OECD member states, thus making it a key economic activity [37]. High ethical standards and efficient procurement is paramount as to manage this large amount of government revenue, therefore both the private and public institutions dealing with procurement activities need transparent collaboration.

A review of articles by Obwegeser and Müller [38], revealed the recurring themes which can be synthesized into a framework of innovation in public procurement, showing the crucial role that procurement plays. Walker and Brammer [39] studied the relationship between sustainable procurement and e-procurement from various practitioners from 20 countries. The authors found that e-procurement and reliable communication with suppliers may help in sustaining procurement and may also hinder buying from small local suppliers if they are not technologically abled.

Cong [40] concluded that there is bigger possibility to understand readers' demand and utilize that data to formulate a book procurement strategy. While there are various problems in the researcher's methodology, such as lack of reader information and singularity of search variables, there is a possibility to integrate data from various search platforms within the library to utilize it book procurement strategy aiming at the readers.

3.4. Supply Chain Performance Review Tools: SCOR Overview

The Supply Chain Operations Reference (SCOR) is naturally a tool released by the Supply Chain Council (SCC, now APICS) in 1996 to integrate business process reengineering, benchmarking, operations measurement into a an integrated framework for businesses to use [41].

The model offers a logical method for identifying, evaluating, and monitoring supply chain performance. According to Huan et al. [41], the framework contains the following aspects:

- Standard descriptions of management process
- A framework of relationships among the relationships
- Standard metrics to measure process performance (e.g., inventory turnover, productivity ratio, customer fill rates, order to cash cycle time etc.
- Management processes that produce best in class performance
- Standard alignment to software features and functionality

As described by Apics [42], SCOR identifies five core supply chain performance attributes: reliability, responsiveness, agility, costs, and asset management. It SCOR model contains a modelling tool, a set of Key Performance Indicators (KPI's) and benchmarking. The model's generic scope has five distinct process elements for management activity namely.

- Plan
- Source
- Make
- Deliver
- Return

Curbelo and Delgado [43] stated that there is a need for a proper management of the supply chain, and this will assist businesses to improve their competitiveness by increasing SC efficiency through optimal use of resources that fulfil the customer need. They further stated that better accuracy in planning and control of the flow of materials and data in the whole value chain improves relationships among segments of the chain, reduce inventory levels and shorten delivery time.

The typical traditional categories of supply chain performance measures of the company include 3 metrics such as service measurement, cost measurement, and Return on Assets [44]. These metrics are described as short-term financial performance measures. In the 2000’s Brewer & Speh [45], stated that there is a need to achieve the balance between non-financial and financial results across short-term and long-term time horizons.

Then SCOR model provides a unique framework that links business processes, management indicators, best practices and technologies in a unified structure to support communication between partners in the supply chain and improve the effectiveness of management and supply chain improvement activities [43].The SCC has a large number of companies including Collins Aerospace, Weir, Express Point, DuPont and many others which are utilizing the SCOR model for strategic performance [46].

3.5. Lean Management

The word ‘lean’ was used in 1980's as authors attempted to describe the success of Japanese manufacturing corporations, the most prominent being the Toyota Production System (TPS) [47]. In general, the literature defines lean management as a set of tools and methods that improve customer value through the reduction of non-value adding tasks and actions at an operational level [48]; [49], maintained by a strategic organisational philosophy of continuous improvement and culture [50]; [51] and [52].

Lean management offers a customer-centric philosophy grounded on five ideologies (define value, identify the value stream, flow creation, introduce pull to customer and pursue perfection) with the goal of waste reduction from of the process [52].

Traditionally lean has been used in the manufacturing world but recently there has been a move to apply lean manufacturing principles in the supply chain management. The indication by Santos [53] further stresses the point that lean thinking organisations have lean manufacturing with the aim of eliminating waste in production processes.

Waste can take form of anything over than the minimum required amount of equipment, materials, parts, and working time that are essential to production [53]. The types of wastes that are being reduced are, overproduction, waiting, transporting, over processing, unnecessary inventory, excess motion, defects as described by Fercoq et al. [54] .

3.6. Lean Supply Chain

Lean has been implemented in many organisations and there is a wealth of knowledge within published in journal articles. The focus of this literature review will be on lean in supply chain related activities. There is growing pressure for organisations to achieve shorter lead times, lower costs, and better quality. This is supported by the research conducted by Al-Aomar and Hussain [55], where the principles of lean management have been incorporated into the supply chain integrative approaches in the hotel industry.

Therefore, in supply chain, lean provides a systematic approach to optimize value stream from suppliers to consumers through elimination of non-value adding activities. Iyer et al. [56] suggest that firms need to focus on the determinants of superior supply chain performance to be more cost efficient and responsive to dynamic business targets.

3.7. Benefits of Implementing Lean Management in Supply Chain

Lean manufacturing has been used effectively by organisations as a wholly new way of thinking the organisations roles in the value chain and improve organisational performance [57]. The lean management strategies are aimed on how to deliver cost effective good quality products quickly [58]. Successful lean management approaches include.

- Toyota’s TPS (Toyota Production System)
- Nestlé’s NCE (Nestle Continuous Excellence)
- Heineken’s World Class Manufacturing

Further research has shown that there are great benefits for the supply chain when it adopts lean techniques; such as sustainability of the industries increasing unit outputs with less inputs through elimination of non-value-added activities to maintain effectiveness and profitability [59].

Gunasekaran et al. [60] also studied the e-procurement adoption in the small medium enterprises (SME’s) in the South Coast area Massachusetts. The survey was employed revealed that the when the SME's adopted the greater use of e-procurement, there were visible benefits and positive organisational performance such as improved process efficiency, revenue increase and process effectiveness. This affirms that the e-procurement is a vital component of general procurement in a supply chain hub.

3.8. Lean Supply Chain Cases

Lean supply chains are constituted by a set of organisations directly linked by upstream and downstream flows of materials and data that work in a concerted manner to reduce costs and waste through efficient focus on customer needs [61]. It is important to further look into how lean has been implemented in the supply chain environment as it will assist in grounding the research to the concept of lean supply chain. This section will provide a highlight of case studies where lean supply chain was implemented successfully.

In a study by Chen et al. [62], lean inventory management was used to realize increased inventory leanness by 60.90% through cost efficient procurement. Inventory leanness is a company's minimization of its inventory comparative to counterparts in the same sector [63]. In this case, customer service levels were also increased with ominously less inventory costs. The total operation time was reduced by 81% by using lean initiatives and radio frequency identification (RFID) technologies to improve the efficiency and effectiveness of the supply chain process. Major tools such as value stream mapping (VSM) were used in this case.

In the aerospace industry, there has been many cases where lean has been implemented effectively and benefits realized. Garre et al. [64] published a paper where the benefits of lean were tabled. The cycle time for the welding process was reduced by 25% for pressure vessel capacity of 500 L (from 48 min to 36 min) and by 26 % for 220L pressure vessel (from 54 min to 40 min.)

In a study by Rahman et al. [65], a manufacturing company through implementing the Kanban system (one of the lean tools), reduced operational costs, wastes, scraps. The company minimized losses and overproduction of stock was controlled with flexible workstations. Although this study was completed when the company was still on the infant stages of implementing lean, it demonstrated the benefits of using lean to optimize the value stream of the company.

In their paper, Afonso and Cabrita [66], proposed a conceptual framework for management of Lean Supply chains which focused on integrating monetary and non-monetary performance dimensions. This conceptual framework expands the current data on lean supply chains and provides indication of how lean supply chain performance assessment [66]. The proposed framework was implemented in a Small Medium Enterprise operating in the fast-moving consumer goods (FMCG) sector in order to better understand the suitability of this conceptual framework. More case studies in lean supply chains are going to be deliberated in detail in 6.3, which is a case study review and adaptations in the current study.

3.9. Lean in Service Industry

Lean management has been implemented dominantly in the manufacturing sector. However, there have been successful implementation of lean management in the higher education sector.

Kazancoglu and Ozkan-Ozen [67] investigated the eight wastes in higher education institutions (HEIs). The authors utilized a decision-making method which included fuzzy decision-making trial and evaluation laboratory.

The findings identify the most occurring wastes as in business schools as repeated tasks, unnecessary bureaucracy, errors because of communication problems, excessive number of academic units and creation of an excessive amount of information.

According to Robinson and Yorkstone [68], the University of St Andrews (UK), saved over £130 000 pounds by developing a new software for process management. As one of the outcomes manifested by implanting lean, the university also saved money by removing job adverts from external websites. The resources used to procure job-advertising services were redirected to the university’s treasury. The internal staff benefited by being capacitated with new skills to manage this process.

Arlbjørn et al. (Arlbjørn, Freytag, & de Haas, 2011) investigated the lean practices in the Danish municipal sector through two questionnaire surveys and three case studies and to elaborate on whether it makes sense to apply the lean concept in a service SCM context. They found out that customers' demands in the municipal sector are driven by public political processes such as elections that shape the customer value and add more complexity when compared to the private sector.

In their exploratory study, Habib and Jungthirapanich [69] found out that there is not much literature addressing the supply chain management for the universities let alone research supply chain as a major element in the academic supply chain for the universities. They provided a new dimension to understand the contribution of supply chain management for prosperity of university processes. They further developed a conceptual model focusing on two main contributions to the end customer of the university such as the society including human resource contribution and research contribution.

Kress and Wisner [70] analysed a supply chain for a library with the view to assess and improve its efficiency. The authors employed an action research methodology to map the supply chain of the University of Nevada, Las Vegas Lied Libraries' information resources. They then developed a supply chain model, analysing it and developing linked performance measures. The major advantage of this journal article is that the model was developed and implemented successfully.

3.10. Industry 4.0

The development of digital technologies brought what is termed the fourth industrial revolution, or Industry 4.0. This revolution can be somehow traced to the ''High-Tech Strategy 2020 Action Plan'' [71]. Digitalization has increased opportunities for improvement in manufacturing and service companies, but it is not clear how to get the best out of these innovations. Already during the third industrial revolution of Flexible Manufacturing Systems, and Computer Integrated Manufacturing, we have seen the technological implementation bringing some improvement, but also many drawbacks.

Industry 4.0 can be termed as the snowballing digitization and automation of the manufacturing environment as well as the creation of a digital value chain to enable the communication between products and their environment and business partners [72]. The envisaged result is that there will be an instantaneous planning of products and manufacturing processes leading to improvements in product quality and decrease lead time. VDMA, Bitkom and ZVEI, the German associations of mechanical engineering, ICT and electrical industry, released a definition for Industry 4.0 [73]. According to them, the term aims for optimization of value chains by implementing an autonomously controlled and dynamic production. By this means, it could complement the established Lean Production to match future requirements.

According to Mrugalska and Wyrwicka [74], the implementation of Industry 4.0 has a huge potential and its application include :

- Focused industry-specific solutions
- increase competitiveness and flexibility.
- increased organisational productivity.

The key concepts underpinning Industry 4.0 are:

- Smart manufacturing
- Smart supply chain
- Smart product Internet of Things (IoT)
- Artificial Intelligence (AI)
- Augmented Reality (AR) and Virtual Reality (VR)

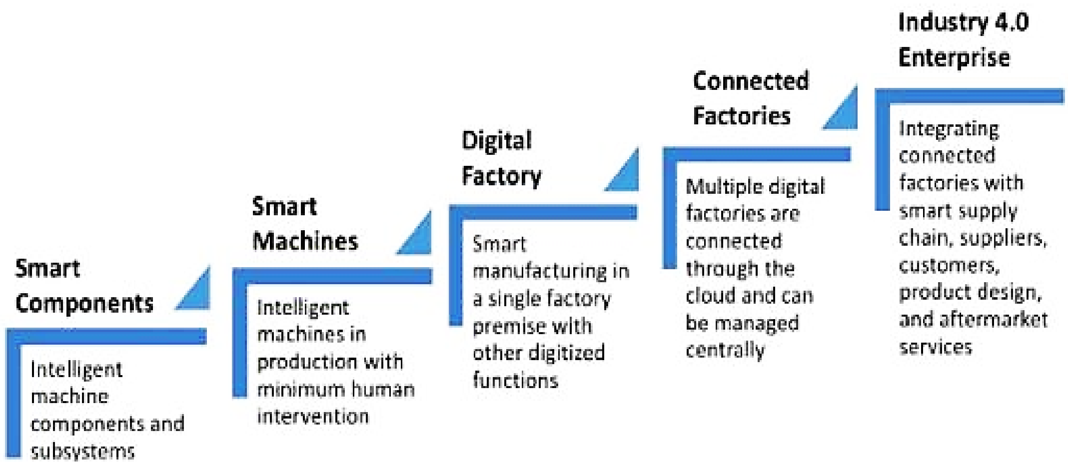


Figure 8: Industry 4.0 Journey

Source: [75]

When integrated and synchronized, these concepts play a key role in Industry 4.0. Smart manufacturing is when an adaptable system of flexible assemblies automatically change the production processes for various types of products and customized conditions [76]. Benefits of this automated system are:

- increased level of product quality,
- improved levels of productivity
- large scale customization of products with very little changeover delays

3.11. Industry 4.0 within the Higher Education Sector

The main activities in education are teaching, learning, research and innovation. These activities are being impacted by the key concepts of Industry 4.0. For example, the use of virtual reality in classroom is now a great tool in clarifying taught concepts and linking the scientific concepts with industry application. Xing and Marwala [77] states that the Industry 4.0 will bring lasting solutions to the education sector. These benefits include:

- Wearables assisted education.
- Embrace massive open online courses (MOOCs)
- Shorter Innovation Cycles
- Internationally-linked degree programs [77]

3.12. Digitalization Enablers in Industry 4.0

Digitalization or digital transformation is a consolidation of procedures of digitization and digital innovation with an aim of improving existing products or services with advanced abilities [78]. Therefore, digitalization explains the synchronisation of organisational business and IT strategies, essentially integrating information technology into the business strategy [79].

The CIPS [80] identified eleven enablers that the organisations and institutions use to transform existing supply chain and procurement practices in manufacturing systems, forming the foundations of Industry 4.0. They form a fundamental basis of existence for Industry 4.0 and its connectivity. The 11 technologies are 3D Printing, Artificial Intelligence, Augmented Reality, Internet of Things, RFID, Robotics, Omni Channel, Sensor Technology, Simulation, Cloud Computing and Big Data. They provide an example where, within procurement, if inventory levels are depleting, an automatic sensory of demand will be created and sent to the ERP System to order materials without of a procurement team member.

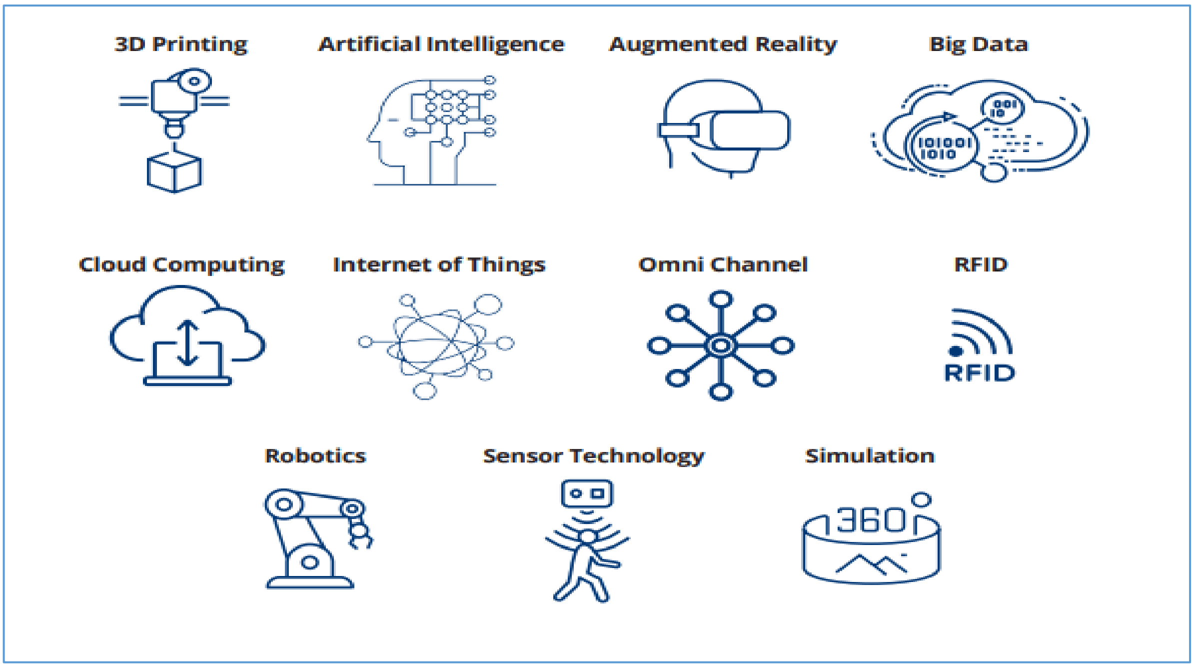


Figure 9: Digitalization technologies in Industry 4.0

Source: [80]

3.12.1. 3D Printing

This is a process by which physical items are produced by depositing materials in layers based on a digital model [81]. The object is then printed using high end printers. This method of manufacturing makes the manufacturing cheaper. Mpofu et al. [82] listed the benefits of using this method as lower cost, shorter production time cycles. This will have an impact on the lead times for procurement processes as they shorten the production time and enable faster delivery of products and services.

3.12.2. Artificial Intelligence (AI)

AI is defined as the capability of a machine to display smart human capabilities such as intellectual, knowledge, design and ingenuity [83]. According to Riahi et al. [84], AI further empower systems to make practical decisions and perform activities automatically without human involvement. The organisations and institutions can then exploit AI for insights in supply chain functions such as demand forecasting, customer management, warehousing, logistics, and procurement. A practical example is an automated invoice processed and approved for a product bought on the ecommerce platform. The university procurement team can then use this for the business-to-business operations with the suppliers.

3.12.3. Augmented Reality (AR)

The Franklin Institute [85] describes AR as an enabler for humans to experience the real-life environment at an exact moment. The objects viewed could be various types of nature and content. In the researcher's point of view, AR can be used to see the showroom of a supplier and provide a clear view of product characteristic thus enabling the procurement team to order correct specifications.

3.12.4. Big Data

Many organisations use internet and systems and generate big amounts of data in the process. This is confirmed by Andrew Kusiak [86], where he commented that intelligent manufacturing has amassed enormous data that is named "big data". Furthermore, the [80] analysed organisations and found that there were already 267 processes or practices that used Big Data. 175 were planned to be using this concept in the 2-to-3-year horizon. Big Data in supply chains and procurement can be used to analyse contracts, expenses, Key Performance Indicators. This facilitates better management of complex outsourcing and supply chain processes efficiency. Additionally, it can be used for demand forecasting and reduce stock outs.

According to Sauter [87], companies mostly leverage their data internally, and not fully utilizing the possibilities that come with such data. Thus, implementing a Big Data focused methodology maximizes current data and can unravel big insights and profits. In procurement, particularly, there are three benefits that come with using big data. They are: -

- Supplier Risk Management: for this benefit, sourcing available trends and events from media, social media for exact phrases covering the procurement items and suppliers can benefit the company to activate dynamic emergency plans, (for instance if there is major heat wave, the ice cream resellers can predict demand increases and avert the stock-outs.
- Improving sourcing price: Big Data analytics can be used to assist is fact-based pricing. For example, an organisation can use the dynamic COVID-19 infection statistics to determine the demand of the alcohol-based sanitizers. The higher infection rates may mean that there is a need to increase supply of sanitizers. A Big Data model can constantly discover the government and communicable

diseases data alerts to renegotiate contracts as soon as there is a significant alcohol price change.

Advancing Organisational efficiency and business objectives: The ERP Systems are robust and normally do not include an updated quotation finder module. Therefor the buyers may need to spend time searching for quotes online or from suppliers. Big data solutions can then link up with the ERP system to find quotations without much involvement of human interaction.

3.12.5. Cloud Computing

Cloud computing as defined by Gupta et al. [88], is a term that offers computing as a service, usually available to an organisation as an outsourced service, where shared information technology is available on demand. The advantage of using cloud computing is that it expedites information sharing across devices and locations thus enabling flexibility of procurement processes without being present at the workplace. It also allows seamless business to business applications enabling intercompany transactions.

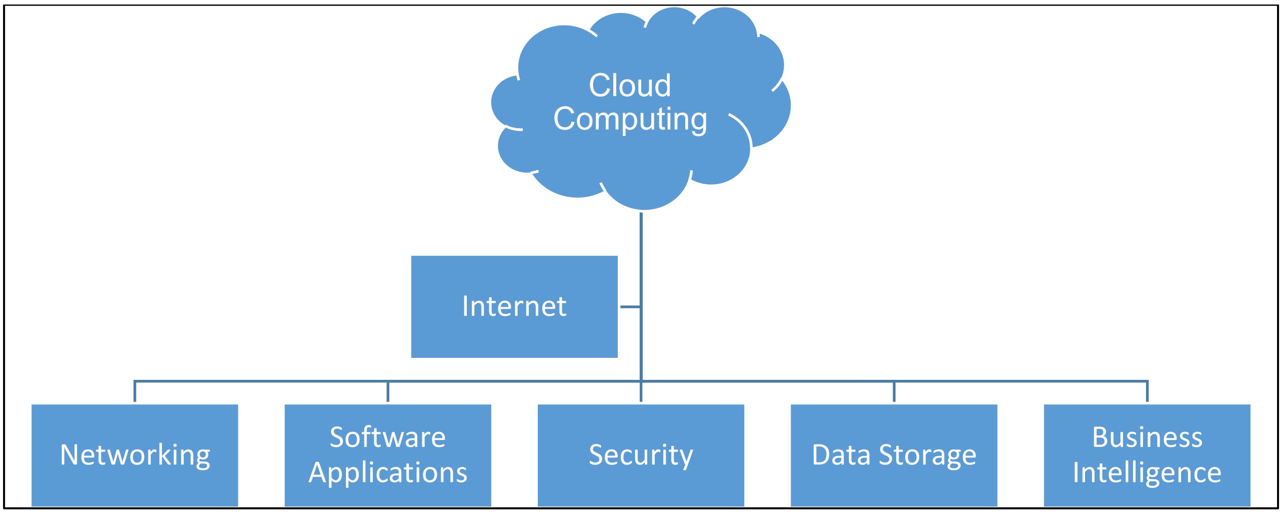


Figure 10: Cloud Computing

Source [88]

3.12.6. Internet of Things (IoT)

IoT plays a major role in enabling Digitalization as substantiated by Tayi [89], who stated that IoT has served as a catalyst for digitizing and automating science and permits the amalgamated collection and analysis of scientific data [89]. The IoT concept was termed by Kevin Aston in a presentation he made at Proctor and Gamble [90]. Defined by Abdel-Basset et al. [91], IoT is an array of physical and virtual objects which are linked together using a communication network and sensors for interior and peripheral interaction.

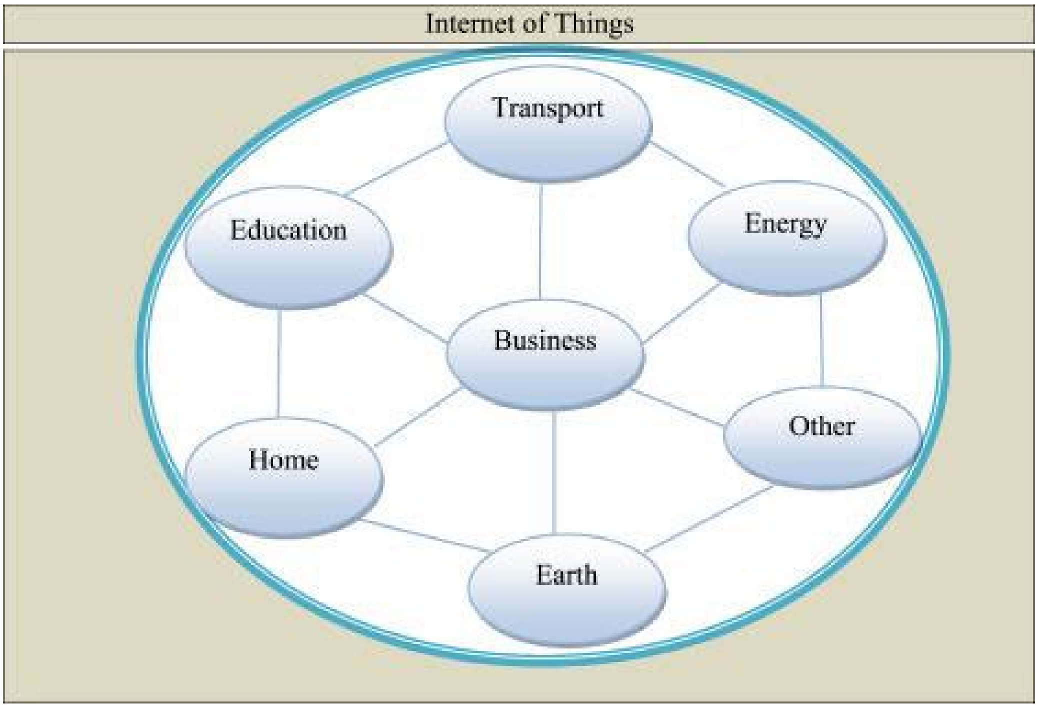


Figure 11: Internet of things application fields

Source:[91]

3.12.7. Omni Channel

Verhoef et al. [92] defined Omni channel as a business tool which links online to physical shop/warehouse transactions. It cuts across the business and organisational functions such as procurement, sales management, information technology and logistics. This industry 4.0 enabler interlinks diverse shopping networks to provide all-in-one user experience.

		Commerce →	Personalisation →	Ecosystem
Capabilities and enablers	Data Analytics	Data, decision making, content management, predominantly aligned by channel	Integrated cross channel data, content management and decision making with strong automation	360-degree view of the customer, including 3rd party data and dynamic usage of predictive or machine learning
	Stores and supply Chain	Cross-channel visibility of inventory, ability to offer buy online for in store pick up	Integrated inventory and delivery (digital fulfilment through stores	Fully omnichannel inventory and delivery with ability to optimize for cost, speed and experience
	Site and Mobile	Strong ecommerce site (desktop and mobile web	Flexible site and app infrastructure with versioning, A/B testing and ability to readily deliver dynamic content and experiences	Best in class ecosystem and UX/UI across multiple applications, platforms and content producers
	People and Processes	Significant coordination across teams (ecommerce, stores, marketing) but discrete Key Performance Indicators	Cross functional teams with strong access to data and shared or integrated Key Performance Indicators (for example, catchment area view)	Customer centric, channel-agnostic organisational structure with omnichannel KPI's (e.g., loan-to-loan value) and strong operations model across teams and partners

Figure 12: Capabilities of omnichannel business model

Source: [93]

3.12.8. Radio Frequency Identification Technology (RFID)

RFID is a technology for wireless identification and article or product traceability [94]. It utilizes uses radio waves to read and capture coded data and store it in chip or tag. This chip is then attached to the product or item. This digital technology is used for real-time and accurate inventory management which can aid reducing inventory levels variance in supply chain.

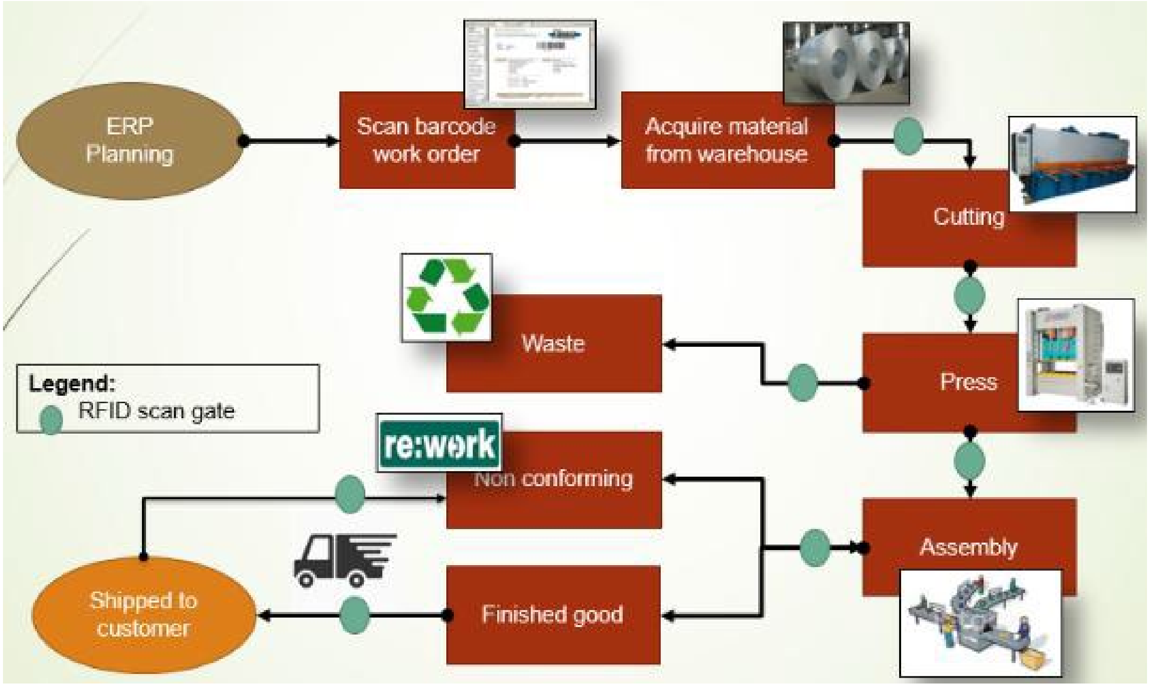


Figure 13: An Example of RFID Use

3.12.9. Robotics

Integrated in robotics is Robotic Process Automation (RPA), which represents software agents that act as people in system communications, and process automation [95]. Robotic process automation includes workflow management systems which is an integral part of Digitalization of processes. RPA is a recent technology utilizing software agents called ‘bots’ that mimic the manual human tasks and perform them in a business process through an automated manner [95].

The advantage of using RPA is that bots use the rule-based applications which perform monotonous and repetitive task in an organised manner throughout the process. Examples of activities that bots execute include data interchange between applications, automated email notifications, and collation of procurement requisitions data from different sources. The use of robotics is greatly applied in manufacturing companies. The robots communicate and perform tasks safely and efficiently especially for monotonous tasks [80]. In essence, automation plays a great role in the used of robotics.

3.13. Enterprise Resource Planning (ERP) Systems

An ERP system is an integrated business management system covering functional areas of an enterprise like logistics, production, finance, accounting and human resources [96]. It is the researcher's view that implementing an ERP is a challenging task and has high-cost implications on the organisations resources as it cuts across all the functions of the company. The inclusion of ERP systems in the literature review is critical because they form an integral part of the procurement systems, and an enabler of processes within the organisation.

3.13.1. ERP Implementation in Large Vertically Integrated Organisations

3.13.1.1. Internal technical personnel resources/labour skills

The large organisations have a very big number of employees, multiple operational sites and larger ICT requirements and therefore require a more focused internal team when implementing an ERP or an EIS. In a company operating in multiple countries this can be a challenge because the level of skills of each country are different and a disruption can occur if the other country has a low level of technical skills.

An example of that is when the company NCQ, a computer manufacturer, was training its employees after implementing ERP in its Chinese facilities [97]. The company discovered that the same training program took twice as much time to complete as at its headquarters in Taiwan [97]. This was due to the lack of IT knowledge and skills in its Chinese facilities, and the implementation decisions were centralized due to this disparity in IT skills.

3.13.1.2. Legacy systems

Certain companies use legacy systems such as Baan and others [98]. The movement to newer ERP systems may be a challenge that requires major financial investment. The companies that use these systems are reluctant to migrate their master data to other ERP's due to possible disruptions which have a huge impact on operations, transactions and the company's financial wellbeing.

3.13.1.3. Under-utilization of ERP systems

Many organisations have expensive ERP systems such as SAP, Oracle and others. However, the internal users still have many spreadsheets and reference points that are outside the frame of the ERP system being utilized by the company [99]. This signals that:

- Certain modules of ERP systems are sometimes too robust and not flexible enough for users to manipulate as Microsoft Excel which is a common and widely preferred by users.
  - Employees still prefer to use old systems that are simple and can be configured for personal understanding and not thinking about the investment that has been made on the ERP system.

The integration of the side references and spreadsheets to the main ERP system are critical to ensure that there is only one point of reference in the whole organisation.

3.13.2. Challenges of ERP Implementation from a SMEs' Perspective

3.13.2.1. Resistance to change

Due to their size and cost structure, the SMEs are small or medium sized and sometimes have pintsized appetite to spend on luxury systems for operations. However, there is a need to innovate and implement systems to ensure growth and profitability. The implementation of an ERP or enterprise information system (EIS) may be met with employee resistance to change. This is due to fear of job loss connected to uncertainties of implementing an ERP system. Teittinen et al. [100], confirmed this from the study to assess the ERP challenges in SME's. The study states that the critical attitudes of employees are also a contributing factor and the necessity of implementing an ERP system needs to be explained well in advance to the employees.

3.13.2.2. High set-up and operational costs

The cost of implementing proprietary ERP software can be very high and it is a challenge for most SME's [101]. The costs include training internal employees, licensing and initial setup costs. These costs may be compared to the return-on-investment but the time to breakeven is long. Using open-source ERP does significantly reduces the investment costs but the cost of training the users and support still exists and the SME owner needs to make a decision on which path to take.

3.13.2.3. Selecting a right ERP vendor

There are various choices of ERP providers in the market and the SME needs to select a good fit for its business. In the Chinese market, the market leaders are in the table below.

Table 1: ERP in Chinese Market

Ranking	Company name	Market Share
1	SAP	16.9
2	UFSoft*	16.2
3	Kingdee	13.2
4	GenerSoft	10.3
5	Oracle	7.5
6	HJSoft	4.3
7	Anyi	3.9
8	Riamb	3.7
9	Other	24.0
	Total	**100**

Source: [102]

CosmetiCo, a company located in China, chose to utilize MOVEX software for ERP and it the package was not totally translated into Chinese [102]. The author further explains that the English words in the user interface confused employees.

“The minus sign of negative numbers is placed after the numbers instead of before them. Moreover, the numbers and other signals in the finance reports were overlapped and became unrecognizable. As a result, MOVEX generated manufacturing and purchasing reports at a lower speed than the previous manual methods." "In the end this was not resolved and CosmetiCo had to choose another provider and restart the project with a local Chinese ERP vendor" [102]. As the SME owner these results can be catastrophic. It can lead to loss of business and revenues. Therefore, it is a big challenge to select a right provider for the business.

3.13.3. Complexity of ERP Systems

A big challenge in the implementation of ERP systems is complexity. It's a big factor to the adoption of ERP and organisations interested in a simple solution rather that the complex interface as they want to focus on profitability and growth [103]. In 2013 a study of the complexity of ERP's and their impacts on productivity in Europe was done as per the table below.

Table 2: ERP packages and their factor scores.

ERP Package/ factor	Dynamics NAV	ORACLE JEDE	SAGE X3	SAP All-in-One
Compatibility factor score	4.17	3.57	3.70	3.63
Complexity factor score	3.29	3.36	3.47	3.30
Efficiency factor score	4.01	4.11	3.77	3.30
Best-Practices factor score	3.71	3.40	3.44	3.41
Training factor score	3.30	3.17	3.24	3.21
Empowerment factor score	3,95	3.78	3.85	4.03

Source: [103]

The complexity factor score is interesting for this case as it reveals the level of ease that users can to discover and exploit all ERP functionalities. In this survey that the lower score the better. Ruivo et al. [103] found that the lower complexity users to extract more value from the system through more frequent and broader use. If the system is too complex it cannot help reaching the business objectives.

3.13.4. Summary on ERP Systems

The inclusion of ERP systems in the literature review is critical because they form an integral part of the procurement systems, and an enabler of processes within the organisation There are many other challenges that both SME’s and large organisations face when implementing the ERP and EIS systems. These include high costs of implementation, risk of investment, choosing the right enterprise system, integrating with external companies and many others. The fundamental target is to select a system that will work better for an organisation. This must ensure that the company grows and the return on investment is realized within a reasonable horizon. This requires commitment from management and employees and proper support and advice from the system vendor.

4. CHAPTER FOUR: RESEARCH METHODOLOGY

4.1. Introduction

This chapter aims to provide a detailed methodology process of how the relevant data was gathered. This study investigates how the integration of industry 4.0 with lean management in supply chain environments will impact higher education to advance productivity and business objectives. There are three dominant approaches to doing research, which includes qualitative, quantitative and mixed-methods research approaches. While qualitative research involves analysing textual data generated from interviews and existing studies, quantitative research consists of different numerical data values from surveys and descriptive statistics. This study took a mixed-method approach to engage a detailed research investigation in answering the following key study questions:

- What are the current practices and efficiencies in the procurement process for research equipment at an institution of higher learning?
- What are the integration models that can be used to implement Industry 4.0 and lean management for an integrated continuous improvement approach?
- How can lean management and industry 4.0 initiatives be implemented in an integrated manner to advance supply chain?
- What are the solutions from lean management and Industry 4.0 that can be recommended to improve supply chain efficiency for the procurement process?

The primary purpose of research is to describe, explain, and validate findings. Therefore, this chapter will discuss the research philosophies or paradigms and then present the research design, research process, method of data collection, and method of data collection data analysis.

4.2. Research Philosophy and Paradigm

Various scholars agree on what a research paradigm and philosophy entail. Tombs and Pugsley [104] view a research paradigm as the beliefs, values and techniques shared by people or members of a given scientific community. A research paradigm can be viewed as a research model for conducting research which a research community has verified and has believed to have withstood the hands of time.

According to Saunders et al. [105], a paradigm is “a set of basic and taken for granted assumptions which underwrite the frame of reference, mode of theorizing and ways of working in which a group operates”. The most popular approaches to a research paradigm are the positivist approach and interpretivism approach. Most researchers use these to define the course of a research methodology, though some approaches have started to stem beside the positivist and interpretivist approaches.

Research philosophy, according to Bajpai [106], is the belief by the research community of the right ways pertaining to data collection of a phenomenon and how it should be analysed and used. Saunders [105] also define a research philosophy as “a system of beliefs and assumptions about the development of knowledge and the nature of that knowledge in relation to research”. Thus, a research philosophy is the reflection of a researcher's important assumptions, which in turn serve as the foundation on which the research strategy is built. Research philosophy consists of many branches on a wider scale of disciplines; however, in the sphere of business studies, there are mainly four research philosophies:

- <u>Pragmatism</u> - its main focus does not rest on cause and effect but on actions and consequences. It is more of a practical approach to problems to arrive at a suitable solution. This approach is characterized by constant change and gives the researcher the freedom to make the necessary changes as long they are in line with the action to be undertaken. Pragmatism can then be quantitative and qualitative in nature.
- <u>Positivism</u> - it is of the belief that society shapes the individual. So positivism value objectivity and proving or disproving hypotheses [16]. Hence it takes a quantitative stance.
- <u>Realism</u> - deals with how things really are, thus values practicality and seeking of facts. So, facts are derived free of external influence but independently. Thus, in realism, it takes a quantitative or qualitative stance, and the methods chosen must fit the subject matter.
- <u>Interpretivism</u> (Interpretivist) - is of the view that individuals shape society and are not puppets to the external social forces [16]. The approach argues the uniqueness of each individual; thus, scientific methods are not appropriate. Hence it involves in-depth investigations and takes a qualitative approach.

For this study, a positivist approach was used to prove if the integration of industry 4.0 with lean management in supply chain environments in higher education can advance productivity and business objectives.

4.3. Positivist approach

Various scholars posit many things when it comes to the concept of positivism. Positivists are of the view that people's opinions, values and beliefs about reality are prone to lies and falsehood and hence might be inaccurate without scientific backing. "*Positivism* is the view that serious scientific inquiry should not search for ultimate causes deriving from some outside source but must confine itself to the study of relations existing between facts which are directly accessible to observation [107]. Thus, it is the rejection of metaphysics and argument that knowledge exists to describe the phenomena experienced.

More so, the methods applied in the positivist approach separates the researcher from the study procedure; hence the views and beliefs of the researcher would not influence the end results of the study [16]. The other reason for choosing this research philosophy is that it adheres to both factual (observable) and measurable data, which is helpful considering that the research undertaken is an observable and measurable phenomenon of one aspect against the other. Hence it is considered a trustworthy approach that fairly represents the phenomenon under study. Therefore, objective inferences are made by analysing the collected data to test the hypotheses and accomplish the research objectives.

The positivist approach is also flexible as it entails both quantitative and qualitative research. The positivist approach prefers quantitative methods such as social surveys, structured questionnaires and official statistics as they have a higher reliability rate. The positivist approach is also of the view that the findings of one study can be generalized to another study of a similar kind regardless of it being carried out in a completely different environment or situation. Thus, following this, the positivist approach clearly represents the course of the study being approached from a mixed-method approach angle.

The figure below shows the research process segmented into six layers by Saunders and Tosey [108]. The layers include the research philosophy, research approach, research strategy, research choice, time horizon, and research procedures.

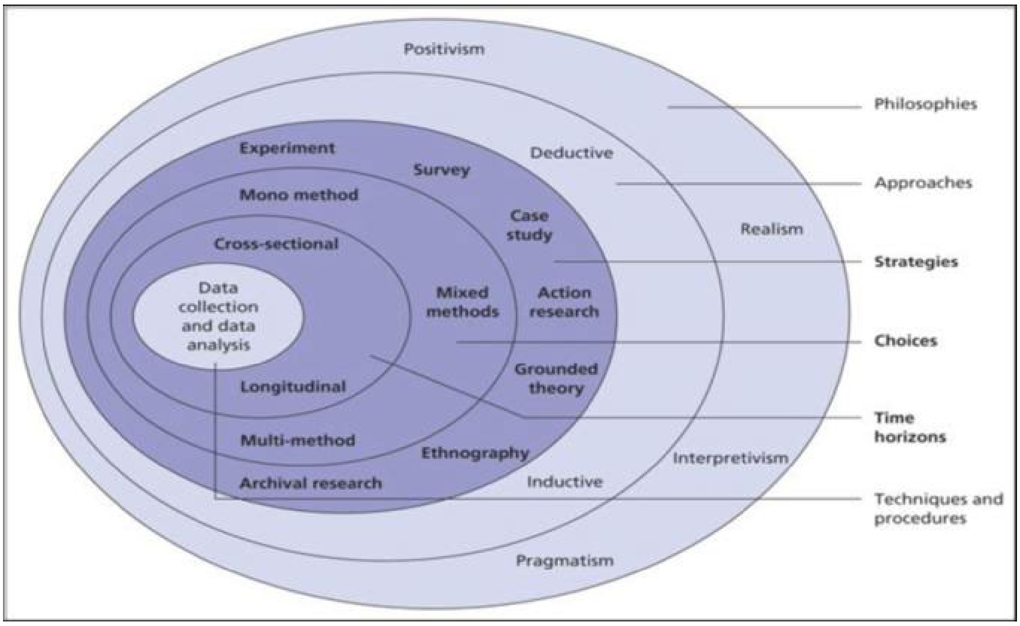


Figure 14: Research process onion

Source: [105]

4.4. Research Design

A research design is a framework or blueprint for conducting the research project, with specifications and precise procedures for acquiring relevant information or data to solve a research problem [109]. So, the reliability and validity of a research study entirely rest on the effective collection of data and how it is also measured, analysed, and interpreted. Thus, a research design unveils how the research questions will be answered [110].

A research design can also be seen as a procedural plan adopted by researchers to answer questions objectively, accurately, economically and with validity. Akhtar [111] stated that the “research design can be considered as the structure of research and the ‘glue’ that holds the different elements in a research project together; in short, it is a plan of the proposed research work.” Thus a research design can be viewed as a detailed plan towards a research study’s completion, the operating variables for measurement, the selection of a sample, collection of data and analyses of the results of interest to the study [112]. A research design exists to aid in avoiding situations in which the evidence gathered does not address the research questions [113]. Hence there is the need to identify a proper approach to achieve accuracy and validity. There are various approaches to a research design. This study made use of the embedded research design.

4.4.1. Embedded Research Design

The embedded research design is a mixed-method design in which one set of data provides a secondary role in research entirely based on other data types [114]; [115]. This is usually effective when different research questions require different data sets. Using both quantitative and qualitative research and data, a researcher can offset any weaknesses presented by using only one data set. This provides rich information on the subject matter. According to Creswell and Miller [114], there are six Mixed Methods Design Strategies which are:

- Sequential Explanatory - this is the collection and analysis of quantitative data then followed by collecting and analysing qualitative data. The aim is to use qualitative results to explain and interpret the findings of a quantitative study.
- Sequential Exploratory entails collecting qualitative data and analysis followed by quantitative data collection and analysis. This is usually used in developing and testing a new instrument.
- Sequential Transformative - this is the collection and analysis of either quantitative or qualitative data first, and then the results are integrated into the interpretation phase.
- Concurrent Triangulation - is characterized by two or more methods used to confirm, cross-validate, or corroborate findings within a study. So, both methods are used to overcome a weakness in using one method.
- Concurrent Nested - this is a nested approach in each one of the methods that guide the project, which is given a priority whilst another is embedded. This is usually present in situations where a different set of questions is to be answered from the dominant.
- Concurrent Transformative - is the use of a theoretical perspective reflected in the purpose or research questions of the study to guide all methodological choices.

For this research, a survey was conducted to obtain the user satisfaction for current procurement processes used in the acquisition of research equipment. This assisted in ascertaining problems and delays in the procurement process for research equipment. The researcher used lean management techniques such as six sigma, the theory of constraints and others to solve the delays in the procurement process.

The qualitative process (development of solutions using lean management techniques and integrating with Industry 4.0 initiatives) followed after the survey responses had been collected. The nature of interventions was qualitative as it is the process redesign informed by survey results. The supply chain for the university was identified and improved using lean management and Industry 4.0 initiatives.

4.5. Research Approach

The second layer of the ‘research onion’ gives closer attention to the main differences between the two approaches presented, which is a deductive and inductive approach. The deductive approach aims at testing an existing theory. So, it is mainly zeroed on scientific investigation. The researcher is studying existing literature, existing theories of a phenomenon under study and then tests the hypotheses derived from theories. As Saunders et al. [105] state, the deductive approach “involves testing a theoretical proposition by the employment of a research strategy specifically designed for the purpose of testing”.

Inductive, on the other hand, aims at developing a theory. So inductive is a procedure for the analysis of qualitative data, moving from specific and simple observations to generalization at a broader scale [105]. For this study, both the inductive and deductive approaches were put in play following the need for the search of new phenomena of the subject matter as well as a comparison from existing literature regarding the phenomenon under study.

4.6. Choice of Methodology

There are commonly three approaches to research, namely qualitative, quantitative and mixed methods approaches. Flick [116] is of the view that qualitative research aims to explore phenomena in their everyday context. So qualitative approach consists of open-ended information usually gathered through interviews, focus groups and observations. So qualitative data is descriptive in nature rather than numerical [117].

Qualitative research seeks to acquire a comprehensive understanding of a phenomenon based on the participants' views [114]. Thus, qualitative is paramount as it brings great insight into everyday human behaviours and experiences.

The quantitative method being the complete opposite of the qualitative approach, explains phenomena using numerical data and mathematically based methods are used to analyses data. Information gathered through quantitative is close-ended information such as the measurement of attitudes, behaviours and performance instruments [114]. As Saunders and Tosey [108] state, quantitative research deals with measurable things and can be expressed in numbers or figures or using other values that express quantity. Thus, the quantitative approach is the analytical progression of figurative data from different fields. This approach is usually quicker in data collection and accommodates a higher or larger sample size, meaning more research data.

The Mixed method approach is a combination of both the qualitative and quantitative approaches. The research used the mixed method approach following the advantages it brings to a research study and the embedded nature of the research itself. According to Creswell and Miller [114], having a mixed approach to research guarantees that one method will do away with the weakness of the other, hence benefiting the research course. For example, in this research, the qualitative approach was able to do away with the delimitation of the quantitative method of not understanding the context or setting in which people behave. The approach also aided in the comprehensive understanding of the research problem. Also, through this method, the implementation techniques that the HEI used to advance supply chain efficiency, by integrating lean management and Industry 4.0 initiatives in the procurement process for research equipment, were investigated.

4.7. Target Population

The target population can be defined as an entire group of people, organisations or items that a sample of the study will be drawn from Carrie and Kevin [118]. The population for the survey was all the departmental administrative staff, 2nd year fulltime doctoral students and postdoctoral researchers in the university that deal with research and are involved in purchasing equipment for research execution. Using the Management Information system of the institution, this was 193 people. This allowed the researcher to explore information from key informants directly linked to the subject matter under study. For the qualitative literature survey, all available literature concerning the same subject matter was considered.

4.8. Sampling

Sampling is the process of selecting individuals or objects which represents the entire population in a study Creswell and Miller [114]. There are mainly two sampling methods: probability sampling and non-probability sampling [105] and each of these have got their strengths, and their delimits.

There is an equal or fair chance of a participant being selected as the other participants for a research study in probability sampling. So, the probability of selection is equal to every participant. According to Datta [119], this reduces systematic error and biases, and there is a possibility of making inferences about the population. However, the technique may be time-consuming and expensive at the same time.

In non-probability sampling, the elements that make up the sample are selected by non-random methods. Meaning the probability of each participant being selected is unknown because of the availability of a range of alternate techniques. The main methods used in non-probability sampling are quota, purposive, volunteer and haphazard [105]. Other methods of sampling include accidental, snowball, simple random sampling and cluster sampling. Purposive sampling involves participants that are deliberately involved in the study based on their involvement in a specific category of the study population.

This study made use of purposive sampling because the researcher decided to choose specific individuals that were considered to be in a position to provide meaningful information towards the completion of the study. Typical case purposive sampling was used as the research study also focused on a typical problem faced by a researcher when procuring equipment following the set supply chain process. So purposive sampling aided in understanding to what extent lean management implementation minimized delays in supply chain processes at an institution of higher learning and to measure the success and failures of Industry 4.0 implementation in the supply chain in the higher education sector.

To determine the sample size, the researcher used a 95% confidence level and 5% margin of error and using Yamane's [120] simplified formula where n is the sample size, N is the population size, and e is the margin of error.

$$\text{Sample Size} = \frac{N}{1+N(e)^2}$$

$$= \frac{193}{1+193*(0.05)^2}$$

$$= 130$$

4.9. Non-sampling Error and Sample Bias

As explained in 4.6, the elements that make up the sample are selected by non-random methods when using non-probability sampling. With probabilities unknown, there is many data problems may arise. Banda [121] stated that the problems that may arise may be related to inadequate Data descriptions, varying objectives, inadequate identification details, vague questionnaires, explanations or directions .

All kinds of bias in this research were avoided, as the participants were not chosen based on gender, age or race but only on the basis of falling within the research pool had an equal opportunity to complete the survey. Validity questions related to department, gender, faculty, type of equipment was used to validate the study, and ensuring that the participants confirm that they are part of the targeted sample.

4.10. Data Collection

Jovancic [117] defined data collection as the "process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer queries, stated research questions, test hypotheses, and evaluate outcomes". In research, there are many data collection instruments. In qualitative and quantitative research, various data collection tools include observation, questionnaires, documentary analysis, experiments, and interviews. This study made use of survey questionnaires as well as secondary data analysis.

In preparation of the survey questionnaires, the following procedures were adhered to as a way of harvesting the most out of the survey questionnaires and avoid any bias which might arise:

- The researcher first created a clear mental picture of the objectives of the survey, also deciding on the research goals. This was done to ensure the course of the research was not diverted from or lost.
- A list of relevant and easy to understand questions pertaining to the subject matter was created, in this case, the questions were on the enquiry of the procurement process for research equipment at the institution of higher learning, the contribution of both lean management and industry 4.0 to the higher education sector.
- The proper and relevant participants were then invited through email in a polite and courteous manner and informed of the nature of the study as well as their right to participation, privacy and withdrawal from the survey. Given the autonomy to ask any questions prior to acceptance.
- The survey questionnaires were then administered through email with a follow up by the researcher through telephone calls to make sure that the questionnaires had reached the intended targets.
- The final data or responses were then gathered and compiled for analysis.

4.11. Data Collection Instruments

4.11.1. Survey Questionnaires

The study made use of survey questionnaires, and they were conducted online. According to Debois [122], a questionnaire is an instrument used for the collection of data which is usually administered orally or written through a series of questions to the participant. This type of research method can be administered physically, or it can be mailed to a participant or on a telephone. Questionnaires may come in the form of open-ended, meaning they allow the respondents freedom and flexibility when providing their answers in research or in the form of multiple-choice, implying that a respondent is offered an option to choose from already predefined answers [123]. A survey is a simple process of gathering data that could involve a wide variety of data collection methods, and the questionnaire is included.

Thus, this being noted, questionnaire surveys are a way of statistical information gathering concerning the attitudes, attributes, or actions of a population through a structured set of questions. This data collection method has its share of benefits and delimits in the research process.

Advantages and Disadvantages

Questionnaires have the advantage in research in that it is relatively easy to administer and is even quick. Large amounts of information or data can be collected from many people in a short period of time, which has also proved to be relatively cost-effective. Questionnaires are thus not time-consuming and flexible to both the researcher and participant as they can be easily distributed and left with the participants to respond to in their own free time.

Questionnaires can also be developed in lesser time than other data collection methods. They have no bounds when it comes to the participants to be understudy as it can be administered remotely online, by telephone or by email. Thus, reducing geographical dependence. As evidence of this study which was carried on online. More so, they do not have time constraints, especially when done online. Online or email questionnaires can be responded to at one's own will and free time as there would be no one waiting at the other end for an immediate answer. Thus, this usually leads to better and truthful responses as the participants will take their time in answering and not be pressured.

Questionnaires are also good for sensitive research. A participant may feel not inclined to answer some questions face to face with the researcher, but in instances where a questionnaire is to be administered, a participant may feel free to express his or her real views concerning a subject matter. To top-up to all the above benefits of questionnaires, this approach has been easy to analyses, especially in this age characterized by many built-in tools.

However, questionnaires have the shortfall of that; there is a chance some of the questions may be entirely ignored, left unanswered or falsely answered; hence the research will be based on misleading information. Another issue of concern is that different participants have varying interpretations of a given set of questions, so this may also present varying responses not rich in data but some misconceptions and misinterpretations of the research questions.

In questionnaires, the participants may also have trouble grasping the meaning of some questions that may be unclear to them or the terminology confusing. As there would be no one to make clear some of these questions, there is bound to be left questions unanswered or wrongly responded to. So, this miscommunication can lead to skewed results. However, such a scenario can be avoided by creating simple questions that are easy to answer, as was the case of this research study.

Why the use of online questionnaires:

- It had low costs in terms of administering and was quick in gathering the desired information.
- It needed less time to prepare as well as forward to the participants and gave the participants the time they desired to respond.
- It enabled the continuation of the research considering the existence of the pandemic, which made a face-to-face interaction challenging.
- The responses were also pre-coded, hence prevented any error, and the data safety was kept as it was in electronic format.

4.12. Secondary Data Analysis

Secondary data analysis is a qualitative data collection method that entails extracting relevant data from existing documents or literature. So secondary analyses derive their data from primary data already collected by someone else. In other instances, it may be that the same researcher who had used the primary data to answer research questions may decide to use the same data but for completely different research. So one set of data can be primary data in one research and secondary in another research [124]. Lin[125] believes that secondary analysis is more advisable when the researcher wants to synthesise existing knowledge, analyse historical trends, or identify patterns on a large scale, which is the case of the research under study. Johnston [126] also argues that it is paramount for a secondary analyst to be knowledgeable on how the existing data were collected for authenticity.

Advantages and Disadvantages

Secondary data analysis is economical. There are instances where data is to be collected from a larger and scattered population; since the data being used by the researcher is already available, it becomes easier and less expensive for the researcher [124]. So, it means the researcher does not have to devote money, time, energy and resources as most of the information will be acquired in already published literature. Though sometimes the secondary data set must be purchased, the cost cannot be the same if a researcher had to gather the data from scratch [127].

In addition, as the data is already available and in cleaned electronic format, it means the researcher is awarded more time to analyses data than being out in the field collecting information [128]. So, it affords a researcher more time to do the research and the analysis of the facts or information present. Thus, there is a greater chance of a final research study rich in data and trustworthy and resourceful following it being gathered from various great minds.

Secondary data analyses also advocate for the need of the researcher to have higher expertise concerning the data collecting instrument. As much as this can be seen as both an advantage and a disadvantage, it compels one to take a professional stance and identify, analyses and conclude one research study from the literature of reputable personnel as well as online sites. Data from people with the expertise about the study being conducted will be referred to and not that collected from other students and uninformative sites.

For novice researchers, the use of secondary data may be the breakthrough they so much anticipated [126]. The approach allows novice researchers to have a pool of information at their disposal. Hence it is a flexible approach and not complicated for new researchers in the research field. However, there are also disadvantages associated with secondary analysis. It may be both an easy as well as a complex method to use, especially for new researchers without the expertise. The researcher's specific research questions may not be answered or be difficult to answer as the primary data set used or identified may be from a different geographical location/region or different time zone [128]. Thus, this poses a great challenge on the part of the secondary analyst.

The researcher has limited control over the contents of the data set as he/ she would not have gathered the primary data. There is a greater chance of identifying data already tainted as the researcher will be not know how the primary data was collected and how well was it also collected. The researcher is not privy of knowing the challenges encountered by the primary data participants and researchers [127]; hence, sometimes, a researcher can falsely read between the lines.

By the use of secondary data analysis, previous history, ways and approaches used for procuring research equipment at an institution of higher learning were identified and analysed visa-vi the data gathered through survey questionnaires. The historical background and developmental stages pertaining to the success and failures of Industry 4.0 implementation in the supply chain in the higher education sector was also identified and analysed. Thus, secondary data analysis was paramount to this research study as analysing historical trends and identifying patterns on a large scale was made possible.

4.13. Pre-Testing of the Survey Questionnaire

The researcher saw the need to pre-test the questionnaires as a way to ensure their efficiency in gathering data. The researcher first moved to forward the survey questionnaires to a selected group of 32 researchers, staff and students across all the faculties, who answered the questions and confirmed that the questions were relevant and applicable to their needs when procuring research related equipment via their emails to retrieve the answers they had forwarded after 24 hours. This enabled the researcher to identify the shortfalls the questionnaires possessed and made corrective measures, especially the questions that proved to be unclear or vague.

The second pre-test was with individuals with the same characteristics as the research population. Individuals with knowledge of lean management, industry 4.0 and supply chain were identified and after asking for their consent, the questionnaires were then sent to their emails. This further enabled the researcher to see the shortfalls in the wording of the questions. Thus, some questions were further rephrased, some deleted altogether, and others replaced as a way to gather relevant and rich data regarding the subject matter. The questions were also categorized so as not to confuse the future respondents to the survey questionnaire.

The third pre-test was then done on a different individual but with the attributes of the sample population. The researcher again forwarded the participant through email the survey questionnaire, checking the time frame he will take and the level of understanding of the research questions. This enabled the researcher to estimate the time frame that might be needed to complete the survey and see if there was any need for question adjustments. The results brought out a higher level of understanding on the part of the participant.

The fourth and fifth pre-test was then with two of the individuals in the actual research study. The researcher did this to ascertain the level of sensitivity the questions may bring to the research under study. This also was the final test to have a clear picture of what to expect from the sample population and their level of understanding to the made simple wording of the questions. Asking for feedback from the participants after the pre-testing and getting a positive response that the wording and approach were understandable became the final draft that was forwarded to all the other research participants.

4.14. Drafting of Questions

The concept of survey fatigue is best described by Porter et al. [129] where, survey fatigue is often cited as one possible cause. The compiled questions were comprised of a combination of those requiring a participant to choose only one answer per question. The questions were presented cogently to reduce confusion for participants through the survey. Majority of the questions were choice based, meaning that they did not need to type answers for most of the questions. This questionnaire was designed made to ensure consistency and reduce survey fatigue.

The questions were then categorized into two categories of efficiency and processing times. The questions related on perception to efficiency:

- Acquaintance with the procurement team
- team responsiveness and order accuracy,
- perception on requisition preparation and approval time
- perception on ERP system efficiency,
- perception on supplier payment delays

The questions related to time and efficiency. They are:

- time taken to prepare requisition,
- time taken to place order after approval,
- product/service processing time by supplier,
- asset registration time.

4.15. Data Analysis

Data analysis is the process of collecting, modelling, and analysing data to extract insights that support decision-making [130]. So, in simple terms, it entails discovering useful data to a research study through the cleansing and transforming of data. In this study, the researcher used Statistical Package for the Social Sciences (SPSS) for the survey questionnaires and then thematic analysis for the qualitative data analysis.

4.16. SPSS Data Analysis

The SPSS is a useful software as it is easy to use and comes with many statistical tests. The thematic analysis allows a researcher to have a detailed understanding of a large pool of data by categorizing them into common themes. The SPSS software package was mainly created for the management and statistical analysis of social science data. After collecting the survey responses, the researcher exported the survey data to SPSS, where SPSS automatically set up and imported the designated variable names, variable types, titles, and value labels, which the researcher used for presentation. The same data was also weighed against the findings from the thematic analysis package.

4.17. Thematic Data Analysis

Qualitative data were analysed using Braun and Clarke [131] latent thematic procedure, which is illustrated in the fifteen-point checklist criteria below:

Process	No.	Criteria
Transcription	1	“The data have been transcribed to an appropriate level of detail, and the transcripts have been checked against the tapes for accuracy.”

Coding	2	"Each data item has been given equal attention in the coding process."
	3	"Themes have not been generated from a few vivid examples (an anecdotal approach), but instead, the coding process has been thorough, inclusive and comprehensive."
	4	"All relevant extracts for all each theme have been collated."
	5	"Themes have been checked against each other and back to the original data set."
	6	"Themes are internally coherent, consistent, and distinctive."
Analysis	7	"Data have been analysed – interpreted, made sense of - rather than just paraphrased or described."
	8	"Analysis and data match each other – the extracts illustrate the analytic claims."
	9	"Analysis tells a convincing and well-organised story about the data and topic."
	10	"A right balance between analytic narrative and illustrative extracts is provided."
Overall	11	"Enough time has been allocated to complete all phases of the analysis adequately, without rushing a phase or giving it a once-over-lightly."
Written report	12	"The assumptions about, and specific approach to, thematic analysis is explicated."
	13	"There is a good fit between what the researcher claims to do, and what the researcher shows to be done – i.e., described method and reported analysis are consistent."
	14	"The language and concepts used in the report are consistent with the epistemological position of the analysis."
	15	"The researcher is positioned as active in the research process; themes do not just emerge."

Figure 15: Fifteen-point checklist of criteria for proper thematic analysis

Source: Adapted from [131]

Following the above steps, the researcher wrote down the research studies questions on paper and read and re-read through the various available literature presented concerning the subject matter identifying the common themes and ideas to later compare them against the findings of the survey questionnaires.

The data was then put into different categories and coded into main and sub-themes. Conceptual labels were put on fragments of data. The themes and sub-themes were zeroed on how lean management implementation minimize the delays in supply chain processes at an institution of higher learning, how Industry 4.0 initiatives implementation to advance efficiency in supply chain processes and also integrated with lean management, the successes and failures of Industry 4.0 implementation on supply chain processes, and how this can be a wake-up call for other organisations and the models that can be used to implement best practices of Industry 4.0 integration with lean management in the higher education sector to supply chain efficiency.

The researcher examined and elaborated on these themes, identifying themes related to each other. From these generated themes, the researcher derived the headings in the presentation of the findings.

4.18. Research Quality Control

Research quality control is the researcher's efforts in making sure there is accuracy and quality in the data collected through the various methodologies. The researcher followed Tracy's [132] criteria for the fulfilment of research quality. Tracy's research criteria are as presented below:

- Worthy topic - This looks at whether the Research topic is relevant, done in a timely manner, whether the research is interesting and finally, if it is of significance. The topic of this study was of great significance as it added to the body of knowledge of lean management, industry 4.0 and supply chain. It can also be a basis of reference for future research as well as an aid for various organisations in need of the same initiatives in their work environment.
- Rich rigor - Is concerned with the study use of sufficient, appropriate and complex theoretical concepts, data, samples and data collection methods and analysis process. The researcher spent enough time in the field and library to gather

enough relevant data and analysed the data with the most appropriate tools for qualitative and quantitative research.

- Sincerity - Entails looking at the transparency and biases associated with the research. In this, the researcher carried out all the research process in a transparent manner, providing clarification where it was needed and was also honest enough to bring out the limitations associated with the study.
- Credibility - This is characterized by the autonomy of inspiring truthfulness in research. The researcher made use of credible secondary sources in reviewing existing literature and in every process of the study to reduce bias. Also, the researcher relied on the credible data at hand to arrive at themes that addressed the research questions.
- Significant contribution - This involves the contribution of the research conceptually, theoretically and practically. The studies aim was to investigate the implementation techniques that organisations can employ to advance supply chain process efficiency by integrating lean management and Industry 4.0 initiatives in the procurement process for research equipment. The study was able to shed light on the whole concept of the subject matter.
- Ethical considerations - this entails all ethical considerations embedded in research and are explored in paragraph 4.10.
- Meaningful coherence entails looking at whether the study met the intended goals and whether the methodology was relevant. Relating to the research study, all the methods used by the researcher addressed the research questions, and the literature reviewed was also relevant to the study.

4.19. Ethical Considerations

The researcher took the following steps in adherence to the ethical considerations associated with a research study.

4.19.1. Voluntary participation

The researcher, prior to the research study, took it upon himself to inform the participants that being part of the research was voluntary, and anyone was free to either participate or refuse. The researcher enabled an atmosphere that did not make anyone feel like he/she was being coerced to be the study participant or did the researcher attempt any deceptive measures to gain the participants' trust and hence compel them to be part of the study.

4.19.2. Informed consent

Informed consent states that an individual must give explicit consent to participate in a study. The researcher, in line with this, made clear to the participants the nature as well as the goal of the research. Consent forms were then issued, which the participants signed as a way of acknowledging that they had understood the nature of the study they had agreed to partake in.

4.19.3. No harm

The no-harm principle states that there is a need to protect the participants at all costs and to focus on the risk to benefit ratio; if the risks outweigh the benefits, then the study should be abandoned altogether or redesigned. The researcher did assess this ratio before the start of the study and made sure the questioning, as well as the mode of questionnaire distribution, did not compromise the participant's position in the process, causing any form of harm to them, be it emotionally, physically or psychologically.

4.19.4. Confidentiality and anonymity

The confidentiality of the information supplied by research subjects and the anonymity of respondents must be respected. The research participants were informed that the information they provided would only be made available to only the researcher and the research supervisor and used only for academic purposes. The surveys provided were not to be put names, and the participants were assured that their departments or job titles would never be mentioned. Pseudonyms were to be used for presentation. For the secondary analysis, the researcher did not attempt to contact any participants for the research. Even though some of the results were already in code names, the researcher assigned new ones to continue upholding the principle of anonymity.

4.19.5. Ethical clearance

The researcher obtained ethical clearance from the appropriate ethics committee and adhered to all ethical principles throughout the study. Furthermore, the gatekeeper permission to conduct research at the university was obtained before research was conducted.

4.20. Chapter Summary

This chapter looked at the research methods adopted for this study. The research paradigm and philosophies were discussed. The study took a mixed-method approach to understand the subject matter, and the qualitative and quantitative approaches used complemented each other. Survey questionnaires were used as the data collection tools as well as secondary data analysis. The research participants were also purposively chosen, targeting those who had experience and knowledge of the subject matter. SPSS and thematic analysis were then used to analyses the data. All this was done adhering to the presented ethical considerations. The next chapter will present the results.

5. CHAPTER FIVE: CONCEPTUAL FRAMEWORK

5.1. Introduction

This chapter relates to the sub-question on models that can be used for integration of industry 4.0 and lean management during implementation. In part, this section touches on the research question below:

What are the integration models that can be used to implement Industry 4.0 and lean management for an integrated continuous improvement approach??

A framework can be referred to an interconnection of set of ideas or theories about a certain phenomenon, its operations or relates to its parts [133]. It forms a foundation for understanding the underlying or correlational patterns of links across actions, philosophies, observations, concepts, interpretations and other components [133]. Additionally, Soni and Kodali [134], describe a framework as a set of basic assumptions or essential philosophies of intellectual derivation in which deliberations and engagements can ensue. For these interconnections of theories to be considered a framework, they must:

- describe the underlying tasks involved in connecting several components of the framework.
- demonstrate the description of sequences of tasks which are required for the designated purpose; and
- show the comprehensive structure of interconnections between elements of system under study, and not only state the fundamentals of the structure [134].

In this research, the researcher utilised a conceptual framework linking two concepts of lean management and industry 4.0. The choice is based on that, by definition, a conceptual framework clarifies, elucidates and validates methodological decisions [135]. Having a conceptual framework fulfils the requirement in the above definition. According to Ngulube et al. [136], a conceptual framework assists in the following:

- provision of coherent research [137]
- provision of a scheme for planning and timing the variables of interest to the researcher

- introduction of explicitness to research process [138]
- provision of research clarity, what it seeks to achieve and procedure of accomplishment [139]
- demonstration of consistency between experimental observations and conceptual decisions [138]; and
- offers a self-audit facility to ensure cohesion and appropriate conceptualisation for research conclusion [138].

There are five considerations or criterions for frameworks as described by Soni and Kodali [134]. These considerations are important in ensuring that it fully complements the purposes explained by Ngulube et al. [136]. These considerations are:

- **originality** – this consideration scrutinizes whether the framework is an adaption of an existing framework or totally new.
- **source of framework** – frameworks can be academic, practitioner grounded [134]. The identification of the source assists in ensuring that the type of framework can be validated by practical implementation.
- **framework verification** – this must be done to ensure that its significance and relevant in a given domain [134].
- **mode of verification** – a framework may be verified using several modes such as case studies, surveys, focus groups, action research, a Delphi study or combination of any of these modes [134]. In this study the survey is used to identify inefficiencies in the procurement process and then the conceptual framework consisting of constructs from Wang et al. [140] and Sony [141].

This present study builds two existing theories by validating the frameworks developed by Wang et al. [140] and Sony [141]. The validation process was done using data collected through a survey, establishing the significance and applicability of the framework in the procurement process for research equipment in an institution of higher learning in South Africa. The need for validation specified by Soni and Kodali [134], is addressed so that the gap between the theory and practice is bridged. This chapter discusses the fusion of the intra-Integration of initiatives in Industry 4.0 by [140] and inter-integration with lean management of [141]. It further discusses the concepts within these models of integration.

5.2. Integration within Industry 4.0

According to Wang et al. [140], there are three categories of integration in Industry 4.0. They are:

- Horizontal (inter-organisational) - synchronization throughout the value chain of the organisation, the suppler network and other external role players in the supply value chain.
- Vertical (intra-organisational) – synchronisation of subsystems within the organisation
- End-to-end engineering integrations – synchronization for customization products and services across the value chain

These integration types are differentiated by the interconnections as explained above and illustrated in Figure 16.

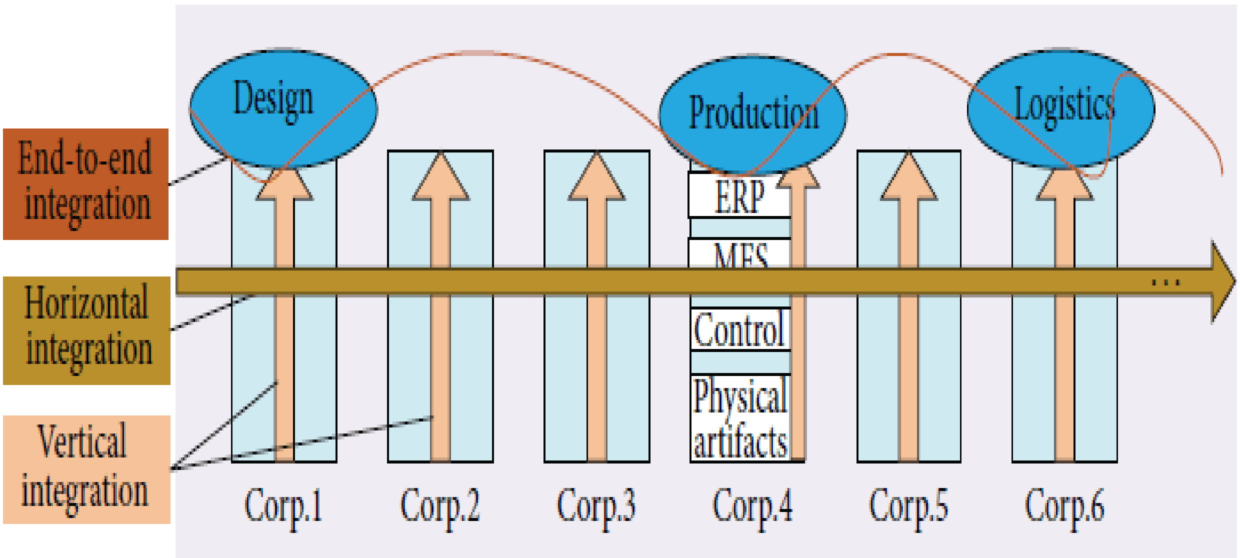


Figure 16: Illustration of three kinds of integration and their relationship

Source:[140]

5.2.1. Horizontal (Inter-organisational)

Horizontal integration include synchronization of value networks to enable collaboration between companies in the supply value chain [142], [71]. For example, a supermarket chain sharing of demand forecast in a digital system digitally to enable the producer to determine the productions volumes [142]. This enables a proper and accurate forecast which decreases the variability from the actual sales. The benefits of a horizontal integration of all systems along the entire value chain is that the customers are able to track the progress of their ordered product [142]. This value chain must be defined in terms of how the customer value is [143]. This is critical before implementing any business improvements.

The horizontal model is evaluated for validity, reliability and objectivity by Pérez-Lara et al. [143] to detect business gaps and opportunities to improve the industrial environment. The authors' stress that in this instrument is not yet fully tested, so in the future, it is intended to apply to the productive sector. Furthermore, the proposals by [142] and [71] do not specifically state how integrations with other existing methodologies will be achieved, hence the need to enhance it for practical application.

5.2.2. Vertical (Intra-organisational)

Originally defined by Schildenfrei [144], the vertical integration deals with the integration of information systems in various organisational hierarchical levels between operations and management. Vertical integration is comprised of various ranked subsystems within the organisation to create a flexible and reconfigurable manufacturing system within the organisation [140]. The autonomous interconnection in these systems is critical and achieved through a smart enterprise resource planning (ERP) system. Big Data plays a critical role in vertical integration [142].

The various ICT subsystems within the organisation are connected to the ERP system. Having a vertically integrated organisation using unified integration and interconnection of all different production processes and steps, the organisation can expects more transparency in their processes [142]. The pitfall with this integration is that it only focuses on mainly production and manufacturing elements. There is a need to further study how it can be expanded to include logistics elements such as warehousing and procurement.

There are challenges in adopting the vertical integration model for Industry 4.0. The challenges include:

- Scaling up of information technology systems and infrastructure – This is because Industry 4.0 utilizes large amounts of data and thus the need for fundamental IT capacity increases [144].

- Breaking Down Silos - Industry 4.0 integration levels require breaking down data and knowledge silos from all departments for optimal integration [144].

5.2.3. End-To-End Engineering Integration

End-to-end engineering integration in Industry 4.0 focuses on the production or provision of customized products and services across the value chain [145].

The end-to-end engineering integration is critical in enabling the creation of customized products and services across the value chain [146]. A typical example of this is a customer using a shoe brand website to custom design their sneakers. The System is enabled with internet browser sensors (cookies). The user is suggested of this service from their habitual use of internet. They can custom design their product and once completed, the order is sent online to the sales for fulfilment. The other elements such as suppliers from different countries will be notified of order quantities for components. This will then be sent for manufacturing or final assembly in the regional factory and then sent to consumer once completed.

5.3. Integration Models of Lean and Industry 4.0

From the three types of integrations within Industry 4.0, Sony [141], developed models where lean management and Industry 4.0 can be integrated. They are:

- Vertical integration and lean management
- Horizontal integration and lean management
- End-to-end engineering integration and lean management

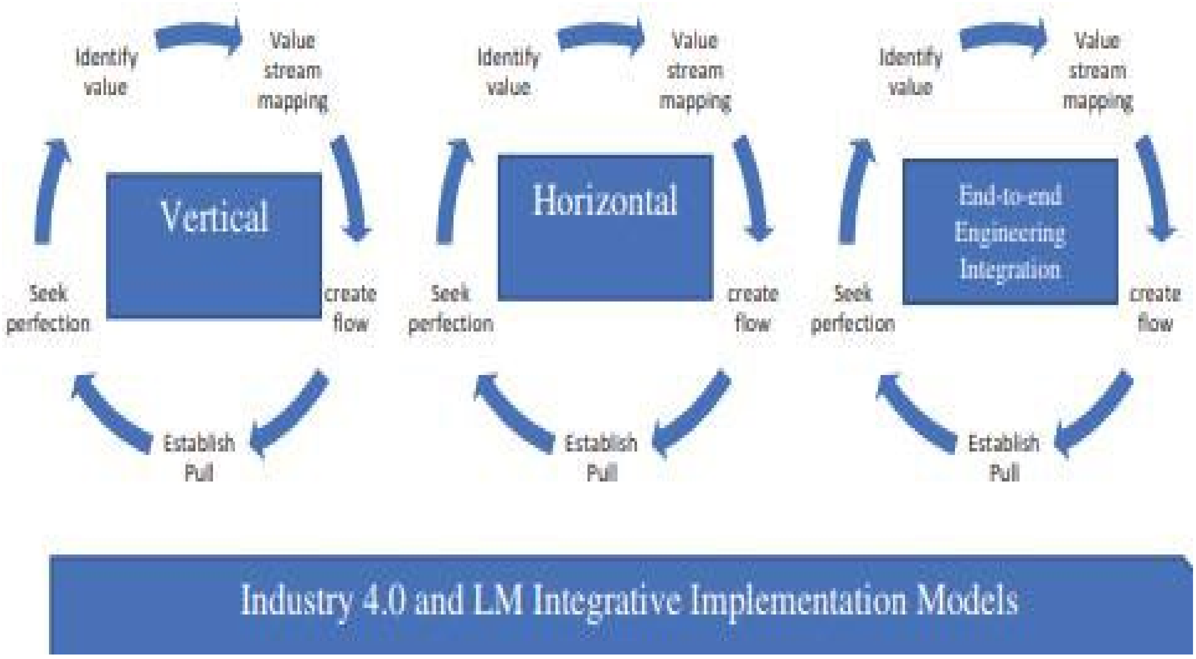


Figure 17: LM and Industry 4.0 Integration

Source: [141]

Prinz et al. [147], argue that lean management, as a methodical approach, is a requirement for Industry 4.0. This is because LM is aimed at value creation through optimizations and standardization while Industry 4.0 is realized by the application of technologies. It is further affirmed by Mrugalska and Wyrwicka [74], that lean production benefits the production companies and manufacturing systems by creating value, reducing waste, and producing good quality products, and improving customers' satisfaction. They further state that in order to achieve full flexibility of production systems, the integration of information communication technology to the production, planning, customer and supplier levels is necessary. They term this integration "Industry 4.0."

It is evident that these two approaches can coexist and support each other for advancement of business objectives. Sony's theoretical model is more structured and robust. The application of this model in industry may be modified for implementation. Since organisations have already implemented lean management, they may adopt the Digitalization solutions that come with Industry 4.0. For example, volatile customer demand can be mitigated by "heinjuka" or levelling in the lean management approach. This can be integrated with cyber physical production systems, which is an important component of Industry 4.0.

Sony [141] proposes a model of integrations for lean and Industry 4.0 and propositions for implementation to test its robustness. The 14 propositions provide a solid base for implementation and recommendation on how these integrations can assist the business with a blueprint for implementing both lean and industry 4.0 simultaneously. They are further presented in Table 3.

Table 3: Integration models of Industry 4.0 and Lean with propositions.

Source: [141]

Number	**Proposition by M Sony** [141]	**Type of Integration**
Proposition 1	While designing the vertical integration architecture through Industry 4.0 for implementing Industry 4.0, defining the value in terms of customer needs for products and services will form the underlying principle for vertical integration [141].	Vertical Integration and Lean
Proposition 2	Value stream mapping of products and services before designing architecture for vertical integration thorough Industry 4.0 of hierarchical subsystems within an organisation will help in removing waste in the integration of CPS which will represent all machines, products, and resources within the organisation [141].	
Proposition 3	The vertical integration of various hierarchical subsystems within the organisation will create a smooth flow process leading to cross-functional cooperation between departments by integration of CPS within each department in a strategic manner using a self-regulated system [141]	
Proposition 4	The vertical integration though Industry 4.0 of hierarchical subsystems within the organisation will drastically reduce the time taken to bring the product into the market enabling a customer created pull system [141].	
Proposition 5	The vertical integration of hierarchical subsystems should create a continuous improvement culture within the overall integrating subsystems within the organisation to improve value to the customer [141].	

Proposition 6:	Horizontal integration of various organisations is designed based on the common and mutually agreed perception of the customer value among the integrating organisations, which the commonly agreed integration strategy is supposed to accomplish [141].	
Proposition 7:	The horizontal integration mechanism can be designed by incorporating VSM, to map the value to the customer by identification of waste (Muda) in the horizontal integration mechanism [141].	Horizontal Integration and Lean
Proposition 8:	The horizontal integration mechanism using industry 4.0 will improve the flow across the cooperating organisation to deliver value to the customer by incorporating smart coordination and regulation systems[141]	
Proposition 9:	The horizontal integration mechanisms using Industry 4.0 will enable the delivery of customized products and services in a shortest possible time based on customer created a pull system resulting in new industry level benchmarks[141].	
Proposition 10:	Continuous improvement culture should be the benchmark across all the horizontally integrated organisations to create a perfect system to deliver optimum customer value by using minimum resources [141].	
Proposition 11:	End -to-end engineering integration requires identifying the value of the product in terms of customer requirements which are further translated into the CPS requirements[141].	End-to-end engineering integration
Proposition 12:	For end-to-end engineering integration the value stream of CPS system requirements using the product-service-system will help to identify the non-value added activities [141].	

Proposition 13:	For end-to-end engineering integration the data from the smart products can be used to design the smooth flow using the CPS [141].	
Proposition 14:	The data from the smart products can be used to create a pull system design using end-to-end engineering integration in a shortest possible time within and external to the organisation[141].	
Proposition 15:	The self-regulating mechanism through smart data from the products in end-to-end engineering will create a culture of continuous improvement[141].	

5.4. Proposed Integrative Framework for Models

The integration model of lean and Industry 4.0 proposed by Sony [141] is built on Wang et al. [140] model, and includes the integration points of lean management with all the three integration of industry 4.0 which are vertical, horizontal integration as well as end-to-end engineering integration models. Sony's theoretical model is more structured and robust.

The application of this model industry may be modified for practical implementation since organisations have already implemented lean management, they may adopt the Digitalization solutions that come with Industry 4.0. The researcher then proposes a combined approach for application that can be used for this study by adjoin the foundations of problem & inefficiencies detection before the combined approach can be implemented. Figure 18 below shows the integrated approach that these models of can be integrated for problem solving in business process improvement.

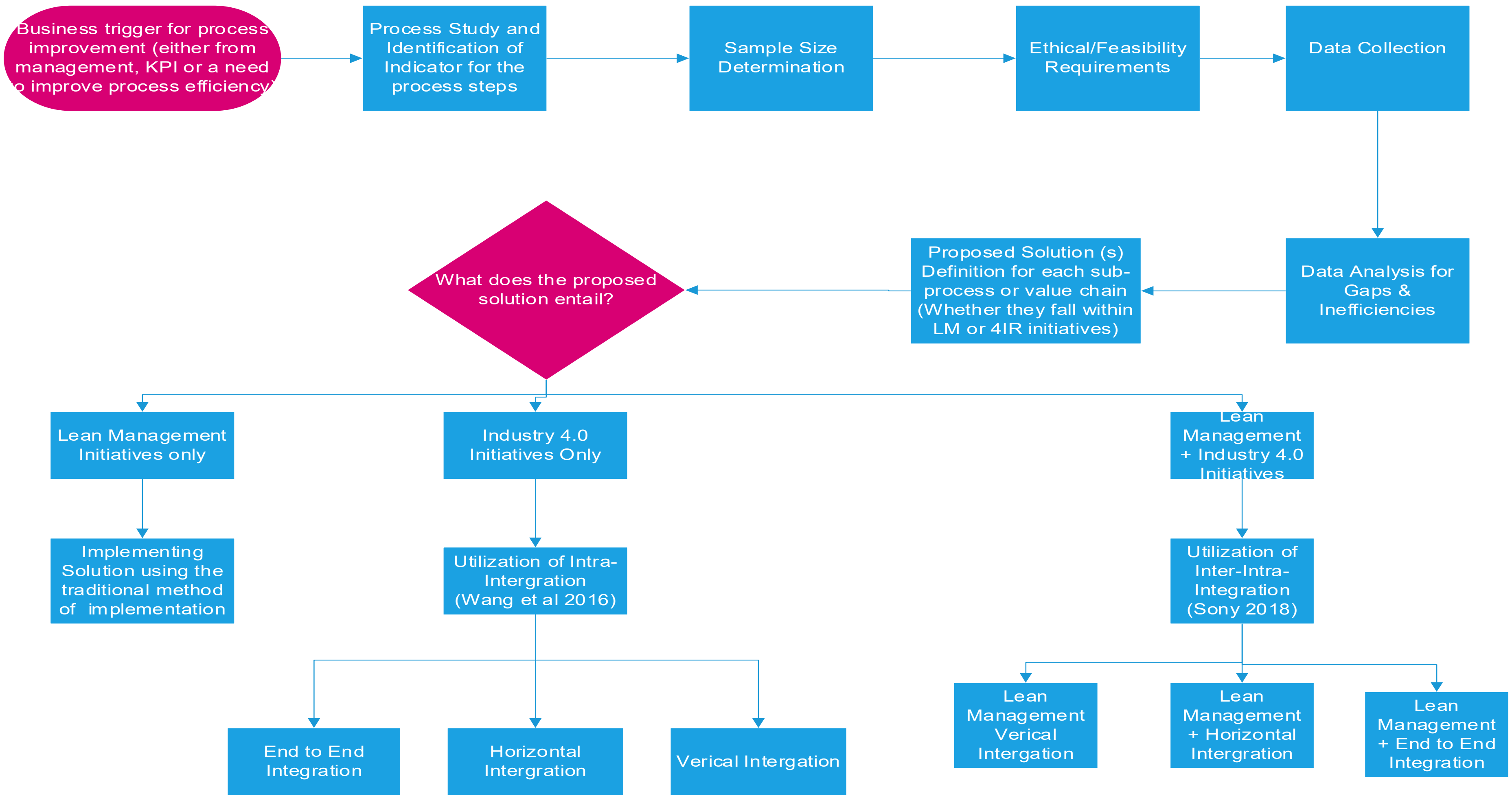


Figure 18: Proposed model of implementation

5.5. Chapter Summary

This chapter provides an understanding of the integration models that guided this study. There are three types of integrations that can be employed to integrated applications of Industry 4.0. They are vertical integration, horizontal integration and end to end. These models of integration are proposals by Wang et al. [140] and are built on Kagermann et al [71].The constructs of these integration models form a firm foundation for building on other continuous improvement techniques including lean management.

This chapter also discusses the challenges in adopting the integration models. The challenges in adoption of vertical integration model for Industry 4.0 include scaling up of information technology systems and infrastructure due to that Industry 4.0 utilizes large amounts of data and thus the need for fundamental IT capacity increases [144]. The challenges with vertical integration within Industry 4.0 also entail breaking down silos as Industry 4.0 integration levels crucially require breaking down data and knowledge silos from all departments for optimal integration [144].

The integration model of lean and Industry 4.0 proposed by Sony [141] is laid out in this chapter. Built on Wang et al. [140] model, it includes the integration points of lean management with all the three integration of industry 4.0 which are vertical, horizontal integration as well as end-to-end engineering integration models. Sony's theoretical model is more structured and robust. The application of this model industry may be modified for practical implementation since organisations have already implemented lean management, they may adopt the digitalization solutions that come with Industry 4.0. Sony [141], further provides propositions (Table 3), that can be used to implement lean and Industry 4.0 applications in an integrated manner. The researcher then proposes combined approach for application that can be used for this study by adjoin the foundations of problem & inefficiencies detection before the combined approach can be implemented.

6. CHAPTER SIX: SURVEY RESULTS AND CASE STUDIES' REVIEW

6.1. Introduction

This chapter focuses on the results of the survey and the review of the case studies of both lean management and Industry 4.0. and discussion of the research results. The first section 6.2, presents the results of the survey, while 6.3 presents the analyses of the case studies.

6.2. Survey Results

6.2.1. Participant Type

Table 4 indicates that 30 (23.1%) of the respondents were researchers (postdoctoral, research fellows and associates), 49 respondents (37.7%) were staff employed at the university, and 51 (39.2%) doctoral students responded. The combination of researchers and staff is 60.8% and students constitute the rest of the percentage. This is a balanced spread of the target sample and shows that most of the research equipment is being bought and utilized by the postdoctoral researchers and staff. A significant 39.2% percent of the respondents were 2nd year doctoral students, proving that are an important part of the sample for survey.

Table 4: Composition of survey participants

	Frequency	Percent
Researcher	30	23.1
Staff	49	37.7
Student	51	39.2
Total	**130**	**100**

Figure 19 shows the graphical representation of the frequencies and percentage of each participant type.

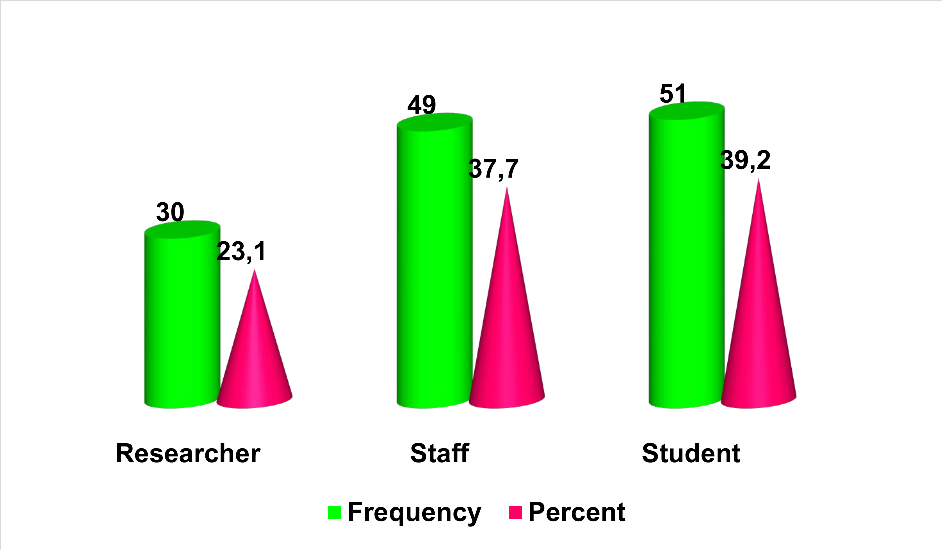


Figure 19: Graphical representation of participants

6.2.2. Gender

Table 5: Breakdown of amounts for respondents by ender

	Frequency	Percent
Female	61	46.9
Male	69	53.1

The survey found that that 61 of the respondents were females and 69 (53.1%) were males as indicated in Table 5. These results show a realistic balance between the two genders with an insignificant gap in the representation of eight respondents.

6.2.3. Race

Table 6: Breakdown of respondents by ethnicity

Ethnicity	**Number of Respondents**
African	60
Asian	9
Coloured	8
Indian	32
White	21

Table 6 indicate that 60 (46.2%) of the respondents were African, 9 (6.9%) were Asian, while 8 (6.2%) were Coloured, 32 (24.6%) were Indian and 21 (16.2%). The major share of the respondents was African, and this is a reflection of the racial composition of university population. This is further illustrated in Figure 21 below.

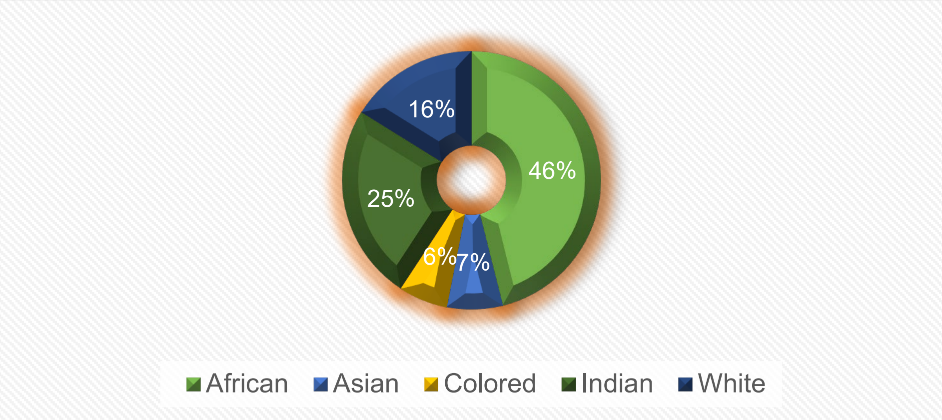


Figure 20: Ethnicity of the respondents by percentage

6.2.4. Faculty

The respondents' faculties were spread into seven, as illustrated in Table 7 and Figure 21. The faculty of Accounting and Informatics accounted for 15% of the respondents in the survey. The results show that 38 (38%), 12 (9%), 21 (16%), 16 (12%),18 (14%) and 5(4%) were for the Applied Sciences, Arts and Design, Engineering and Built Environment, Health Sciences, Management Sciences, Research Innovation and Engagement faculties.

Table 7: Breakdown of respondents by faculty

Faculty	Researcher	Staff	Student	Total
Accounting and Informatics	7	2	11	20
Applied Sciences	11	23	4	38
Arts and Design	2	3	7	12
EBE	5	5	11	21
Health Sciences	1	8	7	16
Management Sciences	3	5	10	18
RIE	1	3	1	5

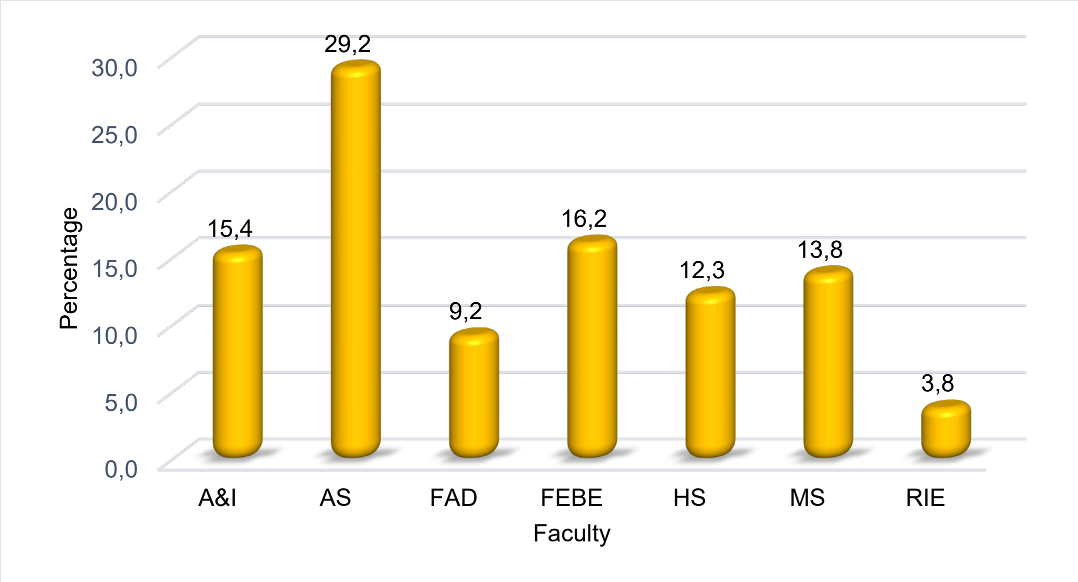
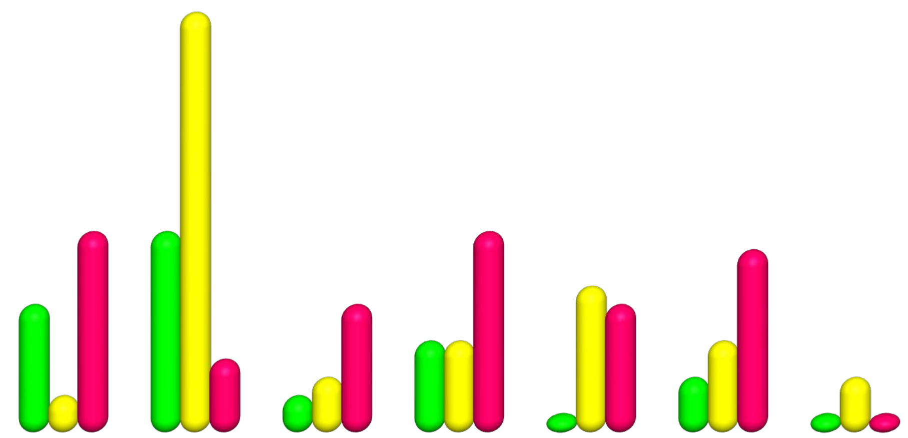


Figure 21: Representation of the respondent per faculty by percentage

Figure 22 shows the composition of respondents by faculty. Out of the total of 20 respondents from the faculty of Accounting and Informatics, 35% were the postdoctoral researchers, while 10 and 55% were administrative staff and 2nd year doctoral students, respectively. In this faculty, the doctoral students slightly dominated the staff and researchers combined, showing that more students were utilizing the procurement process for research equipment such as specialised computers and statistical analysis services.

Out of the total of 38 respondents from the faculty of Applied Sciences, 89% were the postdoctoral researchers plus administrative staff, while 11% were doctoral students. In this faculty, the administrative staff and postdoctoral researchers who responded dominated the students, indicating that the requisition originators were mostly employees of the faculty. This shows the nature of the procurement landscape in this faculty, which is characterised by strict internal controls.



	Accounting & Informatics	Applied Sciences	Arts & Design	Engineering & Built Environment	Health Sciences	Management Sciences	Research Innovation and Engagement
Researcher	7	11	2	5	1	3	1
Staff	2	23	3	5	8	5	3
Student	11	4	7	11	7	10	1

Figure 22: Composition of respondents by faculty

For the Arts and Design faculty, out of the total of 12 respondents, 42% were the postdoctoral researchers plus administrative staff, while 58% were doctoral students. In this faculty, the doctoral students who responded slightly dominated the employee respondents combined, showing that more students were utilizing the procurement process for research equipment such as camera lens, editorial services, transcribing equipment and statistical services.

For the Engineering and Built Environment faculty, out of the total of 21 respondents, 47% were the postdoctoral researchers plus administrative staff, while 52% were doctoral students. In this faculty, the doctoral students who responded slightly dominated the employee respondents combined. The research equipment and services procured ranged from laptop computers, pliers and reactor parts.

For the faculty of Health Sciences, out of the total of 16 respondents, 50% were the postdoctoral researchers plus administrative staff, while 50% were doctoral students. In this faculty, there was a balance of respondents from the faculty employees and students. The respondents from Management Sciences, 44% were staff and researchers combined and the rest of the percentage of respondents were doctoral students. Lastly, the respondents from the Research, Innovation and Engagement sector, 80% were university employees (staff plus researchers), while 20% were students affiliated to this sector. This is characteristic of the RIE sector as it dominated by employees supporting research activities rather than students.

6.2.5. Acquaintance with the Procurement Team

This question was probing if the respondents knew the contact persons at procurement and team structure. This is critical in knowing who to contact for follow up of requisitions and purchase orders. Table 8 below indicate that 62 (47.7%) of the respondents knew the procurement team and structure, 19 (14.6%) were not sure. Forty-nine (37.7%) were did not know the procurement team and who to contact for purchase order tracking and other queries. This is a cause of concern and solutions will be presented on the recommendations part.

Table 8: Respondents on knowing the procurement team.

Knowledge of the procurement team	Frequency	Percent
Maybe	19	14.6
No	49	37.7
Yes	62	47.7

6.2.6. Responsiveness

This question was enquiring the perception the respondents had on responsiveness to queries and order placement communication by the procurement team. This is critical in for the confidence of the team and plays an important role for self-evaluation of the team for continuous improvement. Figure 23 indicates that 34 (26.2%) of the respondents perceived the procurement team as always responsive. The results show that for mostly responsive, rarely responsive and sometimes responsive options, the frequency and percentage were 35 (26.9%), 25(19.2%) and 36(27.7%) respectively. The combined 46.9% of the respondents perceived the procurement team to be sometimes and rarely responsive, thus not very confident of the responsiveness of the team. This is addressed in the solutions part of the recommendations.

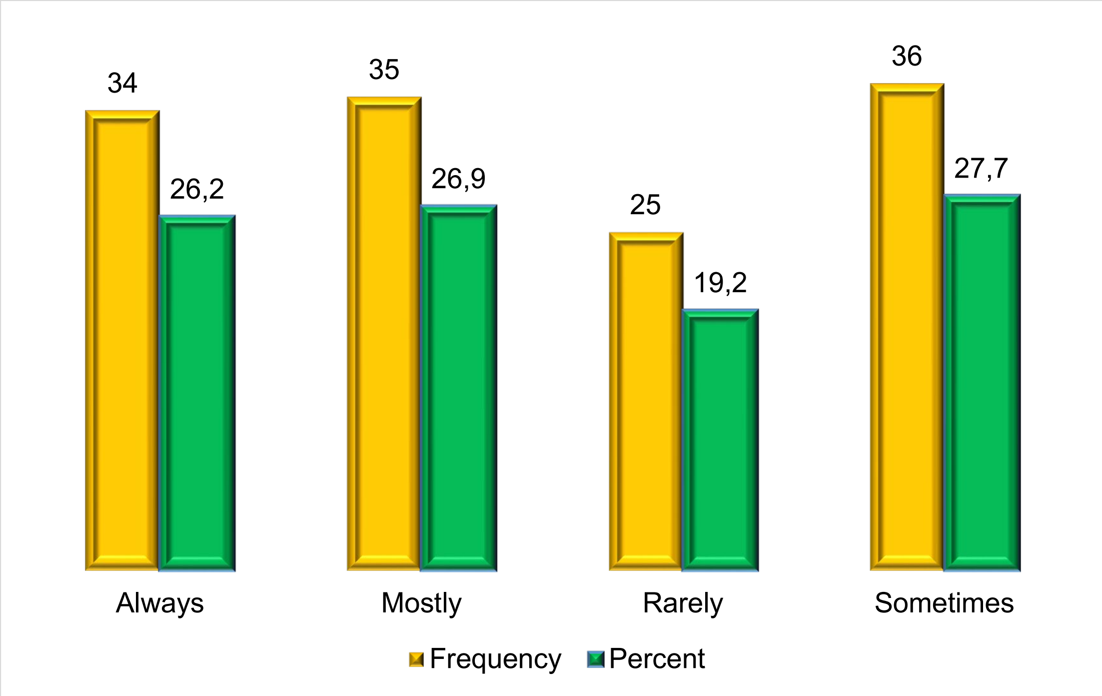


Figure 23: Graphical Representation of the perceptions on responsiveness

6.2.7. Order Accuracy

This question was enquiring on order accuracy of the requisitions. An accurate order is critical in ensuring that the right research equipment is delivered. Figure 24 indicates that 41 (31.5%) of the respondents observed the procurement team as always accurate. The results show that for mostly, rarely and sometimes accurate options, the frequency and percentage were 45 (34.6%), 15(11.5%) and 29 (22.3%) respectively. The combined 33.8% of the respondents perceived the procurement team to be sometimes and rarely accurate, thus not very confident of the accuracy of the team. This is addressed in the solutions part of the recommendations.

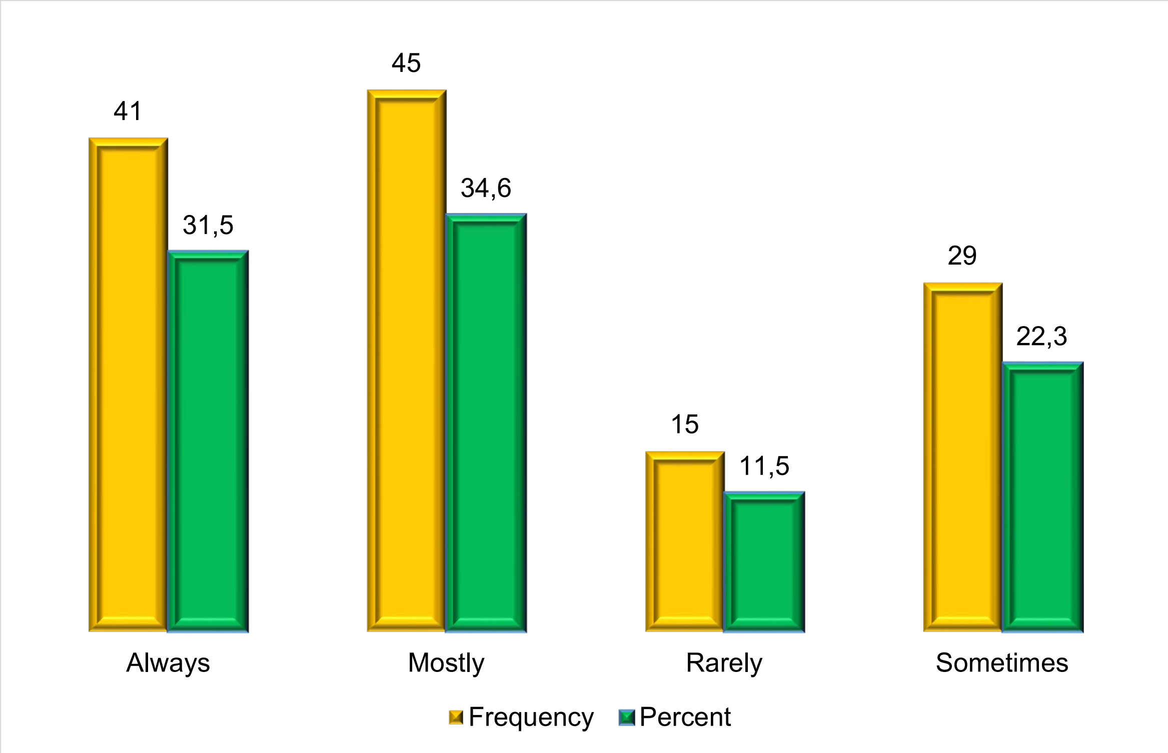


Figure 24: Graphical Representation on order accuracy

6.2.8. Satisfaction with Requisition Approval Time

This question was on whether the respondents were satisfied or dissatisfied with the time taken to approve the requisition by the management in terms of the delegation of authority. Table 9 and Figure 25 indicate that 98 (75%) of the respondents were satisfied with the time taken to approve the requisition by management. Thirty-two respondents (25%) were dissatisfied with the time taken to approve the requisition by management. Most of the respondents were satisfied, 25 % is a significant percentage and warrants some interventions.

The issues that the respondents raised on time taken to approve requisition were inefficient administration, various bottlenecks starting with the technical staff, sickness of senior managers due to covid-19 leading to not always available for signatures. The other issues include lateness of requisitions from administrative staff. One responded raised an issue that his requisition was never submitted on time, until all the quotations were expired and had to restart the process again. The tender process for other research equipment took longer than expected and therefore the approval process kicked in late. Some respondents cited unavailability of petty cash which delayed the procurement of items less than R500. The interventions on these issues is addressed in the recommendations section of this thesis.

Table 9: Results on Satisfaction with requisition approval time.

	Frequency	Percent
Dissatisfied	32	24.6
Satisfied	98	75.4

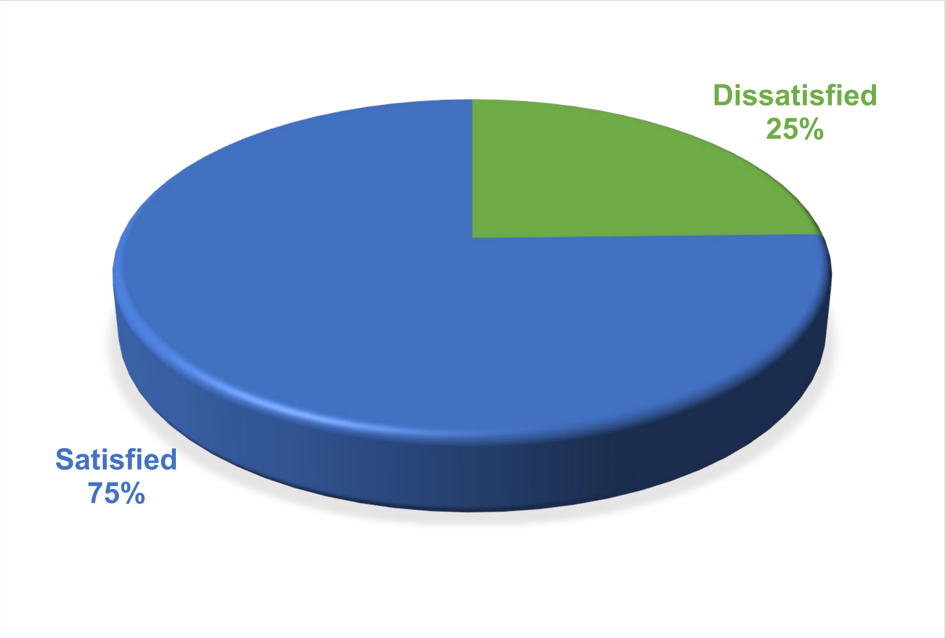


Figure 25: Graphical Presentation on Satisfaction with requisition approval time.

6.2.9. Satisfaction with Order Processing Time

This question was on whether the respondents were satisfied or dissatisfied with the time to process the requisition internally.

Table 10 and Figure 27 indicate that 98 (75%) of the respondents were satisfied with order processing time. Thirty-two respondents (25%) were dissatisfied with order processing time. While most of the respondents were satisfied, 25 % is a significant percentage and warrants some interventions.

Table 10: Satisfaction with requisition approval time.

	Frequency	Percent
Dissatisfied	32	24.6
Satisfied	98	75.4

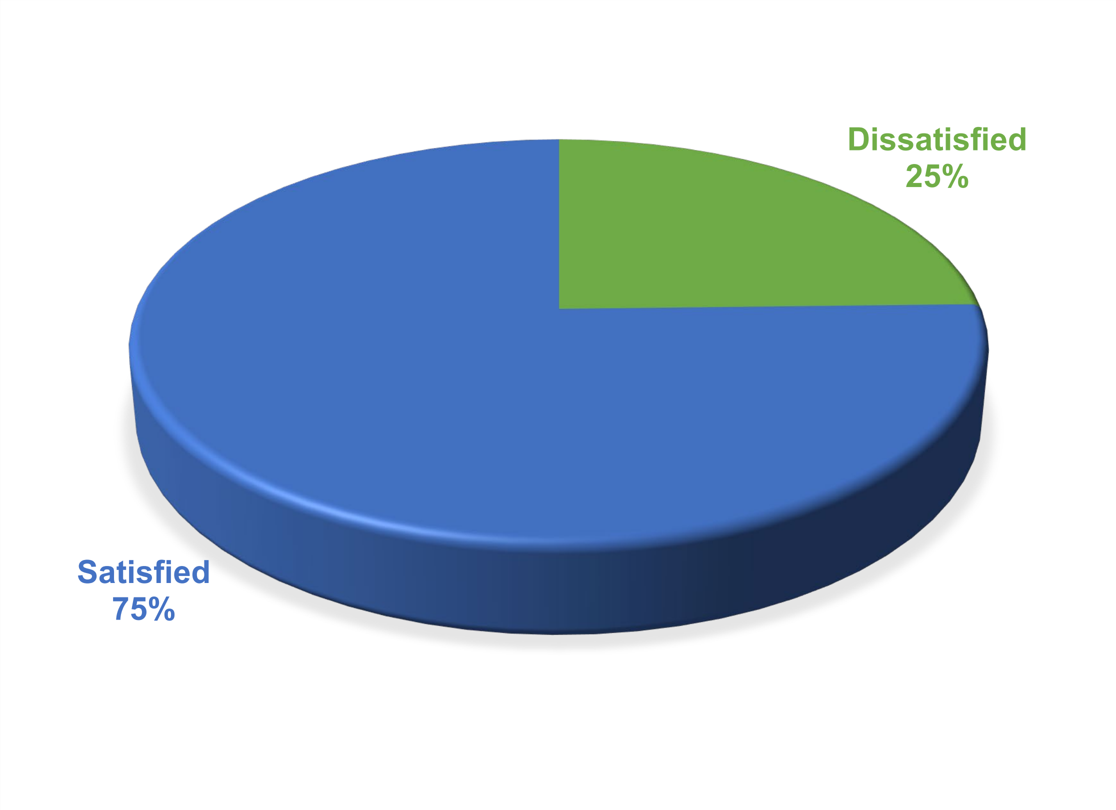


Figure 26: Graphical Presentation on Satisfaction with order processing time.

6.2.10. ERP System

This question was to ascertain whether the respondents knew the system they used to order research equipment. This question also investigates the extent in which the existing ERP Procurement module is being used. Full system usage is critical in ensuring that the organisations get the optimal return on investment. For this study, three options were given to the respondents namely:

- Manual process – using the manual paper requisition forms.
- ITSS – digital online ordering via the university's system called ITSS.
- Hybrid – A combination of the two methods of ordering, necessitated by the nature and value of the research equipment or service sought.

Table 11 and Figure 27 below indicate that (16%) of the respondents utilized the Hybrid process and 55% used ITSS, while 27% used the manual process. The 2% of respondents were not sure which system was used for research equipment. This may be caused that sometimes the orders are handled by the administrative staff thus the respondent not knowing which system was used. The manual process was used by

27% of the respondents which is a significant percentage and interventions are addressed in the recommendations part.

Table 11: Frequency and Percentage of type of system used.

	Frequency	Percent
Hybrid (Manual+ ITSS)	21	16
ITSS	71	55
Manual Process	35	27
Not sure	3	2

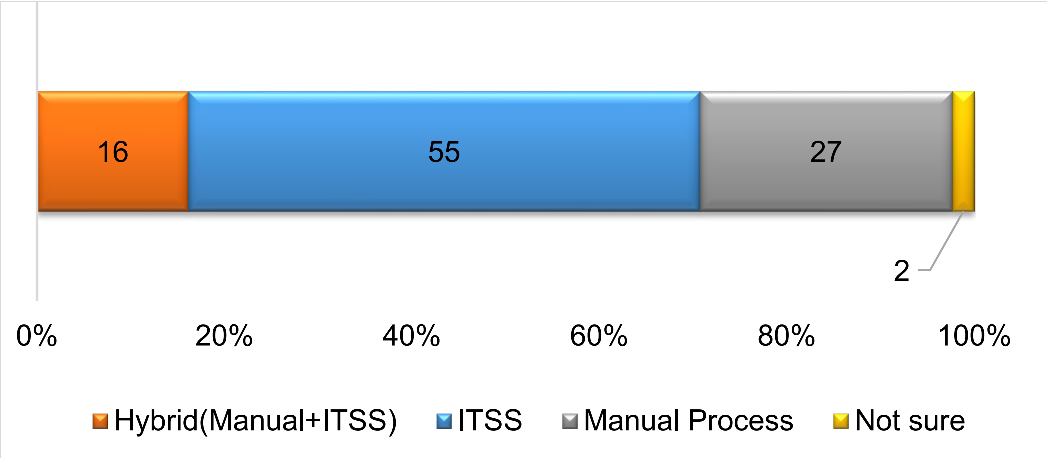


Figure 27: Graphical representation of type of system is used for ordering.

6.2.11. Satisfaction with Order Processing on ERP System

This question was on whether the respondents were satisfied or dissatisfied with order processing system. Table 12 and Figure 28 indicate that 104 (80%) of the respondents were satisfied with order processing system that they utilized. Twenty-six (20%) respondents were dissatisfied with order processing system used. While most of the respondents were satisfied, 20 % is a significant percentage and warrants some interventions.

Table 12: Satisfaction with order processing system

	Frequency	Percent
Dissatisfied	26	20
Satisfied	104	80

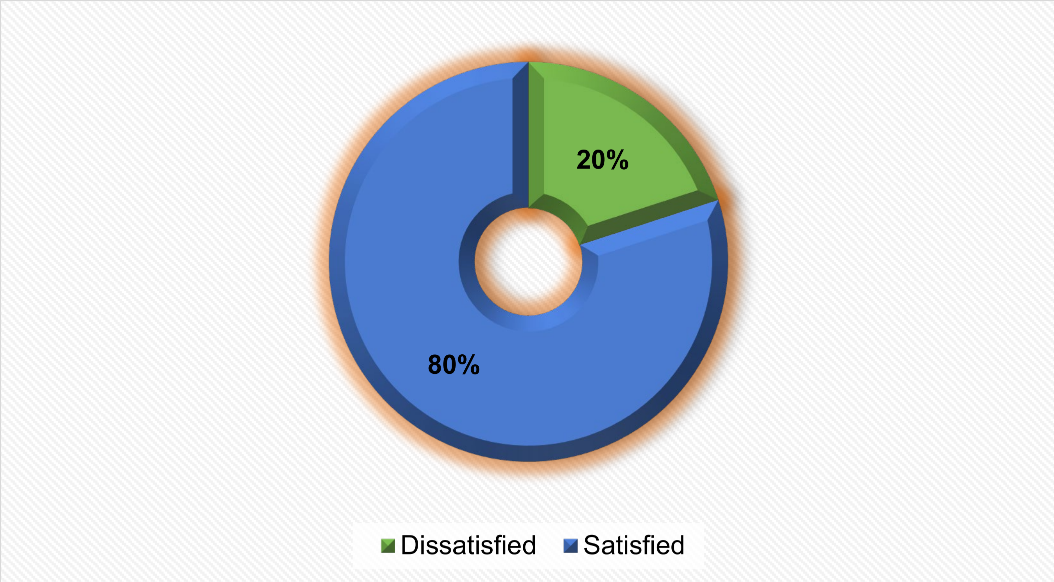
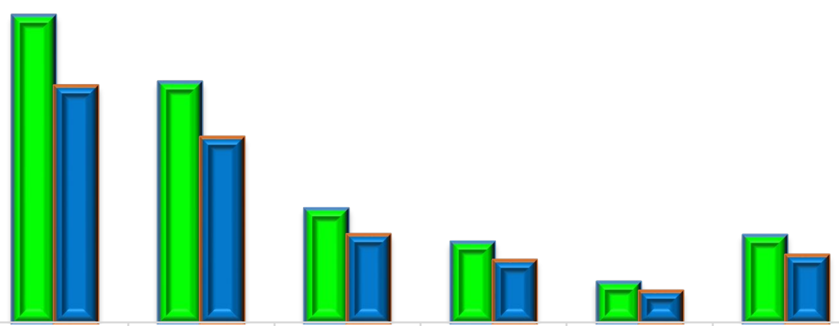


Figure 28: Results for the satisfaction with order processing system

6.2.12. Requisition Preparation Time

This question was poised to ascertain the time taken to prepare the requisition by the initiator or originator. Figure 29 indicate that 46 (35.4%) of the respondents took less than 1 hour to prepare the requisition. For 1-3 hours, 3-8 hours, 1-2 days, 8-24 hours, and more than 2 days options, the frequency and percentage were 36 (27.7%), 17 (13.1%) , 6 (4.6%) , 12 (9.2%) and 13 (10%) respectively. The combined 76.2% of the respondents took 0-8 hours to prepare the requisition. This is a good indicator that there were few challenges in preparing the requisitions and quotation documents.



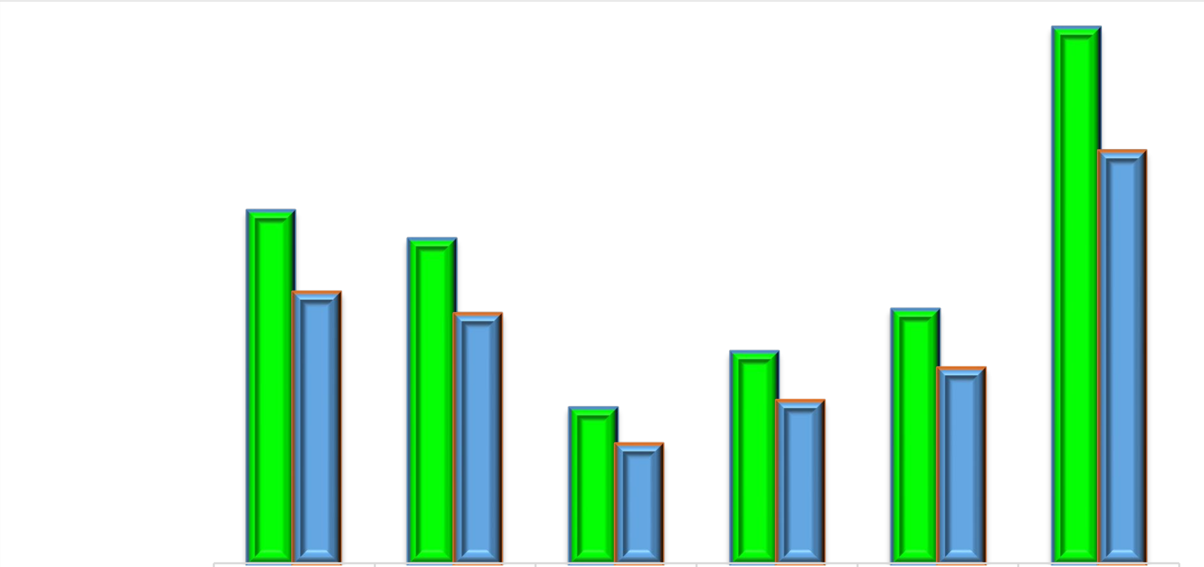
	Less than 1 hour	1 and 3 hours	3 - 8 hours	1-2 days	8 -24 hours	More than 2 days
Frequency	46	36	17	12	6	13
Percentage	35,4	27,7	13,1	9,2	4,6	10,0

Figure 29: Results for requisition preparation time

6.2.13. Requisition Approval Time

This question was poised to ascertain the time taken to approve the requisition by the approved by the approver as per the delegation of authority diagram in Figure 2 before being sent the procurement team.

Figure 30 indicate that 25 (19.2%) of the respondents had their requisitions approved in less than 1 hour. For 1-3 hours, 3-8 hours, 8-24 hours, 1-2 days and more than 2 days options, the frequency and percentage were 23 (17.7%), 11 (8.51%) , 15 (11.5 %) , 18 (13.8%) and 38 (29.2%) respectively. The significant 29.2% of the respondents had their requisitions approved after 2 days. The interventions on this will be addressed in the recommendations section.



	Less than 1 hour	Between 1 and 3 hours	3 - 8 hours	8 -24 hours	1-2 days	More than 2 days
Frequency	25	23	11	15	18	38
Percent	19,2	17,7	8,5	11,5	13,8	29,2

Figure 30: Results for requisition approval time

6.2.14. Order Entry Time on the System After Approval

This question was poised to ascertain the time taken to enter the order in the system after approval by the procurement team. This is the conversion of a requisition to a purchase order. It includes the budget control process.

Table 13 and Figure 31 indicate that 22 (17%) of the respondents had their requisitions converted to purchase orders between 0 and 3 hours. For 3-8 hours, 8-24 hours, 1-2 days, 2-7 days and more than 7 days options, the frequency and percentage were 18 (14%), 39 (30%), 22 (17 %), 13 (10%) and 30 (23%) respectively.

Table 13: Results for the time taken to enter the order after approval.

	Frequency	Percent
1-2 days	22	17
2-7 days	13	10
3 - 8 hours	18	14
8 -24 hours	39	30
Between 0 and 3 hours	8	6
More than 7 days	30	23

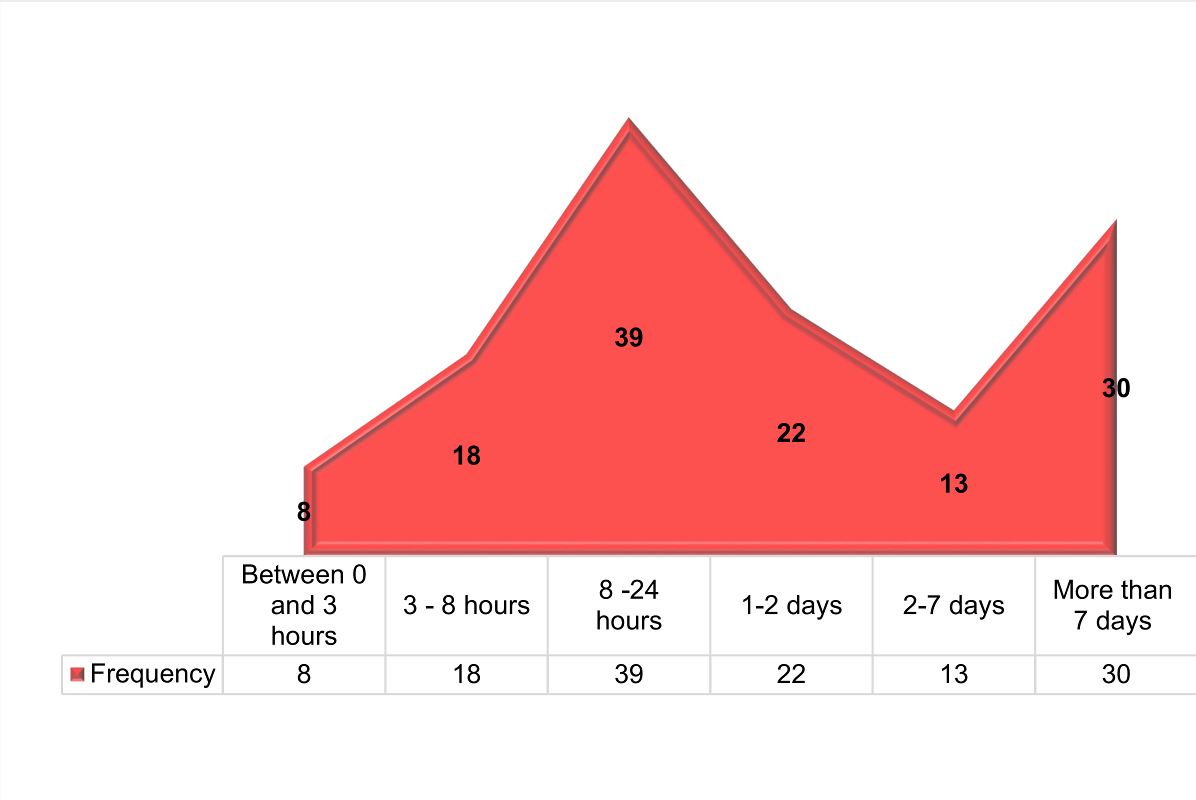


Figure 31: Graphical Presentation of the order entry time

The significant 67% of the respondents had their requisitions converted to purchase orders in between 0- 2 days. For the rest of the respondents, this was more than 2 days. From the raw data of the survey, the nature of these items or services bought was complex and high value (as per the delegation authority), thus explaining the delays while waiting specification confirmations.

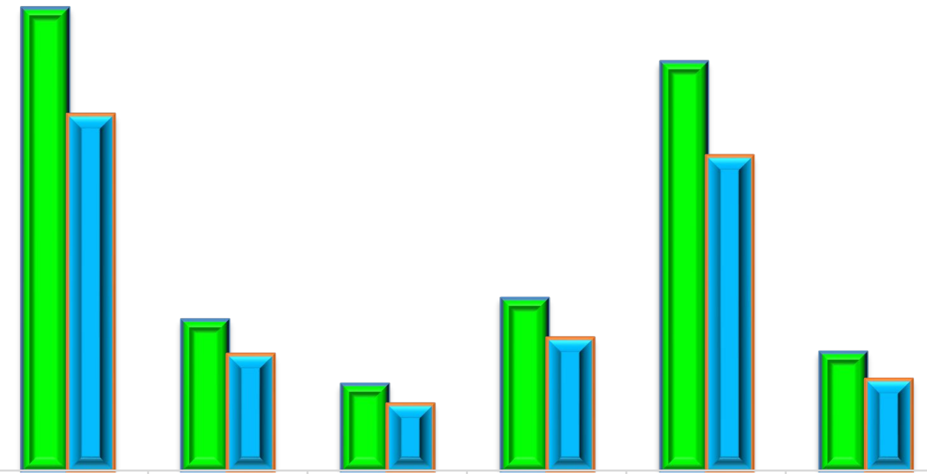
6.2.15. Time Taken to Release Purchase Order to Supplier

This question was poised to ascertain the time taken to release the purchase order to the supplier. Table 14 and Figure 33 indicate that 38 (29%) of the respondents had their purchase orders made available to supplier between 0 and 1 days. For 1-2 days, 2-7 days, 1-2 weeks, 2-4 weeks, and more than 4 weeks options, the frequency and percentage were 43(33%), 16(12%), 14(11%) , 8(6%) and 11(8%) respectively. The significant 74% of the respondents had their purchase orders released between 0 to 7 days. For the rest of the respondents, this was more than 1 week. From the raw data of the survey, the nature of these items or services bought was complex and high value, thus explaining the delays while waiting specification confirmations.

The causes of delays in the release of the purchase orders to suppliers include correction of item codes by the procurement team, long process of signing documents, invoice delayed from supplier due to price fluctuations, difficulty in getting the quotations for specialized equipment, wrong amounts on invoice from supplier. The recommendations' part deal with solutions around these issues.

Table 14: Time taken to release purchase order to supplier.

	Frequency	Percent
Between 0 and 1 day	38	29
1-2 days	43	33
2-7 days	16	12
1-2 weeks	14	11
2-4 weeks	8	6
More than 4 weeks	11	8
Total	130	100.0



	1-2 days	1-2 weeks	2-4 weeks	2-7 days	Between 0 and 1 day	More than 4 weeks
Frequency	43	14	8	16	38	11
Percent	33	11	6	12	29	8

Figure 32: Time taken to release purchase order to supplier.

6.2.16. Product/Service Processing Time by Supplier

This question was poised to ascertain the time taken for the supplier to manufacture the items or provide the service after the purchase order has been released. Table 15 and Figure 33 indicate that 30 (23%) of the respondents had their items manufactured or service made ready by the supplier between 0-7 days. For 1-2 weeks, 2-7 days, 1-2 weeks, 3-4 weeks, 7-10 weeks, 11-20 weeks and more than 20 weeks options, the frequency and percentage were 39 (30%), 25 (19%) , 9 (7%) , 5(4%) and 4 (3%) respectively. 53% of the respondents had their items manufactured between in less than 2 weeks.

For 19 percent of the respondents, the supplier produced their items between three and six weeks. For the rest of the respondents, this was more than 11 weeks. From the raw data of the survey, there were delays in supplier payment and due to the nature and high value of items, some were delayed in the tender committee process. One of the possible factors that may affect the processing time by the supplier is that some order quantities are too small, the supplier may have to wait for similar items and combine several orders for production.

Table 15: Time taken for manufacture item or service provision.

	Frequency	Percent
Between 0 and 1 day	18	14
1-7 days	30	23
1-2 Weeks	39	30
3-6 weeks	25	19
7-10 weeks	9	7
11-20 weeks	5	4
More than 20 weeks	4	3
Total	**130**	**100**

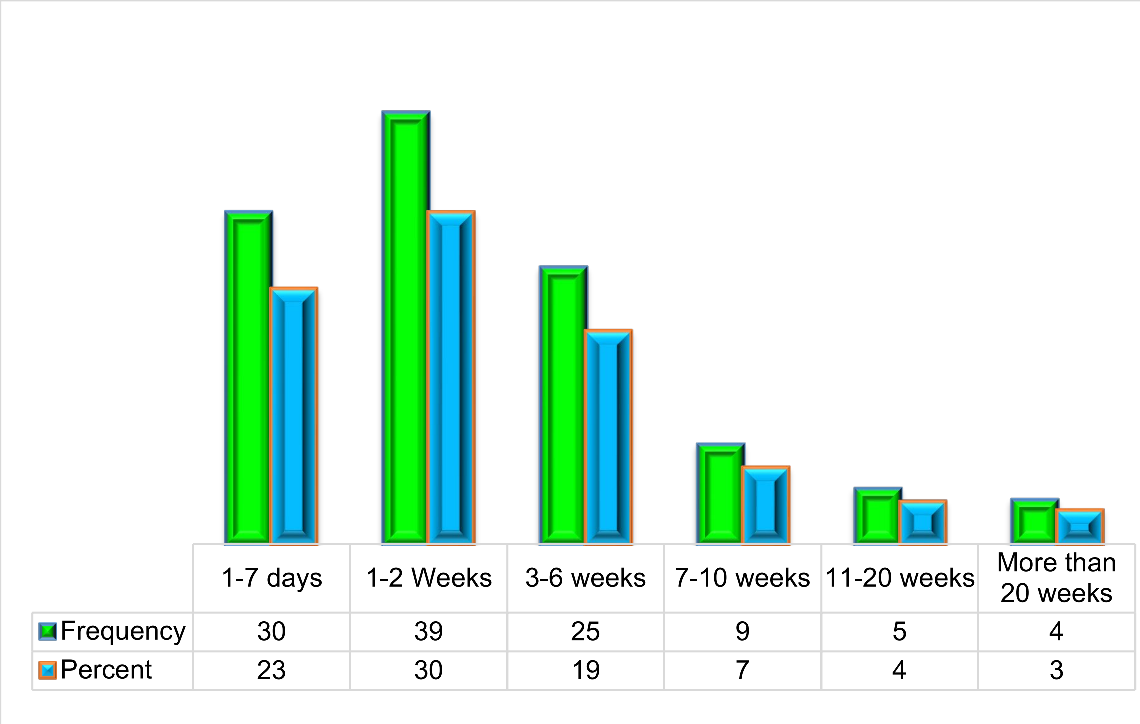


Figure 33: Time taken for manufacture item or service provision.

6.2.17. Supplier Payment Delays

This question was poised to ascertain the number of respondents who had their research equipment delivered late due to supplier payment delays.

Figure 34 and Table 16 indicate that 31 (24.7%) of the respondents experienced supplier payment delays while 99 (76%) did not. Supplier payment delays is 24%. This is a noteworthy point to develop solutions around.

Table 16: Number of respondents who experienced supplier payment delays.

	Frequency	Percent
No	99	76
Yes	31	24

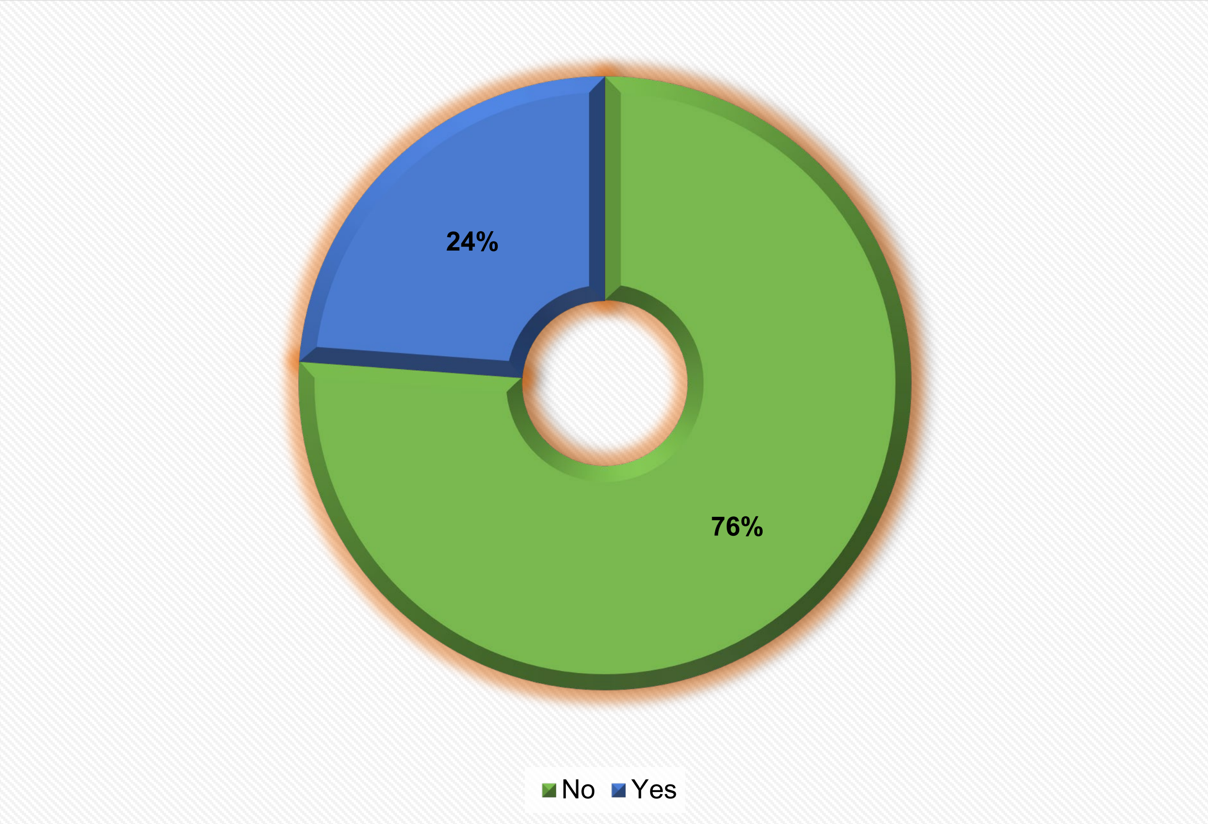


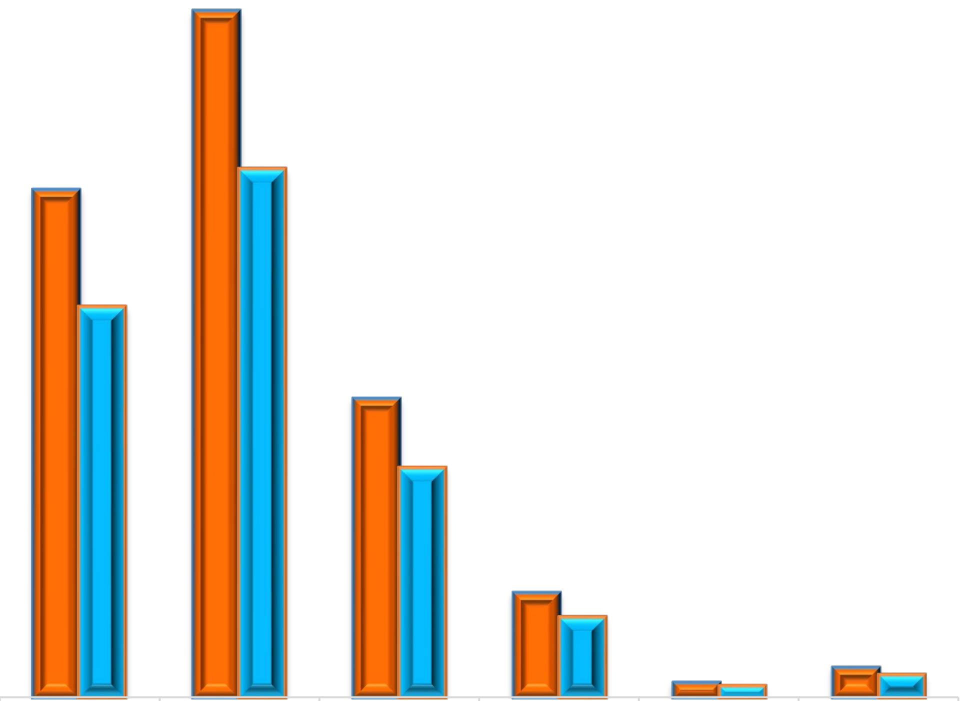
Figure 34: Number of respondents who experienced supplier payment delays.

6.2.18. Order Delivery Time by Supplier

The results for this question depict the time taken to deliver the item after manufacturing. The four options were presented to the respondents to choose the time taken for their specific item purchased.

Figure 35 indicate that 34 (26%) of the respondents had their items delivered by the supplier after manufacturing, between 1 to 7 days. For 1-2 weeks, 3-4 weeks, 7-10 weeks, 11-20 weeks and more than 20 weeks options, the frequency and percentage were 46 (35%), 20 (15%) , 7 (5%) , 1(1%) and 2 (2%) respectively. Eighty percent of the respondents had their items delivered in less than 2 weeks.

It took between three and six weeks for suppliers to deliver items for 15% of the respondents. For the rest of the respondents, this was more than 11 weeks. From the raw data of the survey, there were delays in delivery time and due to COVID19 delays in the harbours and freight vessels.



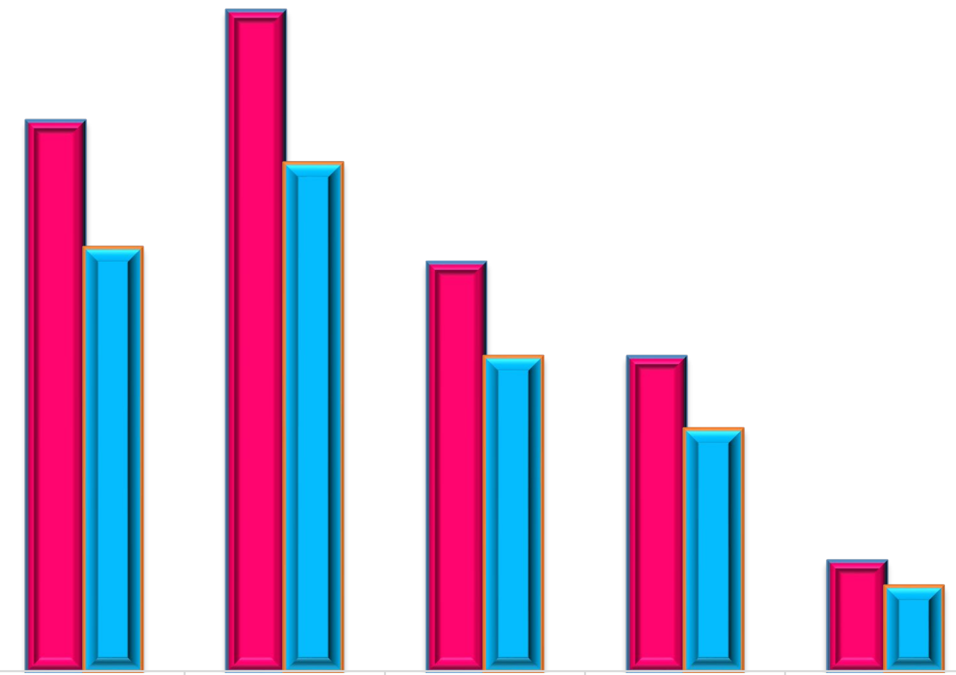
	1-7 days	1-2 Weeks	3-6 weeks	7-10 weeks	11-20 weeks	More than 20 weeks
Frequency	34	46	20	7	1	2
Percent	26	35	15	5	1	2

Figure 35: Time taken to deliver item or service after the manufacturing.

6.2.19. Asset Registration Time

The results for this question depict the time taken for the item to be allocated an asset number and tagged on the asset register. Figure 36 indicate that 35 (26.9%) of the respondents had their items registered on the asset registry by the Assets Department between 0-1 days. For 2 to 7 days. 1-2 weeks, 3-5 weeks, and more than 7 weeks options, the frequency and percentage were 42 (32.3%), 26 (20%), 20(15.4%) and 7(5.4%) respectively. 59.2% of the respondents had their items registered on the asset registry in 1 week. It took between one and two weeks for items to be tagged for 20% of the respondents.

For the rest of the respondents, this was more than 2 weeks. One of the problems observed is that for the equipment purchased during the COVID19 pandemic, the items took longer to be registered on the asset register. This was mainly due to remote working schedules for the researchers, students and staff. When the Assets department physical came to offices for tagging, the equipment custodians were either working at home or not available to open offices.

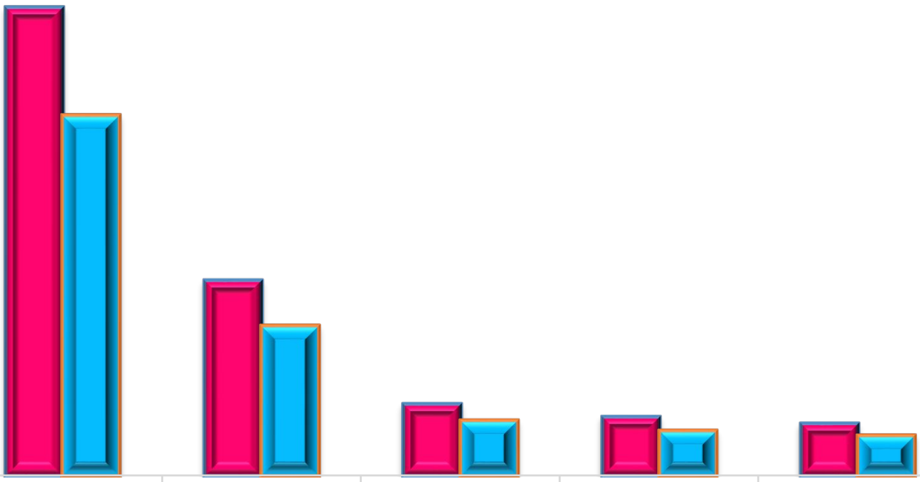


	Between 0 and 1 days	2-7 days	1-2 weeks	3-5 weeks	More than 5 weeks
Frequency	35	42	26	20	7
Percent	26,9	32,3	20,0	15,4	5,4

Figure 36: Time taken for an asset to be registered on the asset register.

6.2.20. Installation Time

The results for this question depict the time taken to install the equipment for research use. Figure 37 indicate that 72 (55%) of the respondents had their items installed for use between 0-1 days. For 2 to 7 days. 1-2 weeks, 3-5 weeks, and more than 5 weeks options, the frequency and percentage were 30 (23%), 11(8%) , 9(7%) , and 8(6%) respectively. Seventy-eight percent of the respondents had their items installed for use in 1 week. It took between one and two weeks for items installed for 8% of the respondents. For the rest of the respondents, this was more than 2 weeks.



	Between 0 and 1 day	2-7 days	1-2 weeks	3-5 weeks	More than 5 weeks
Frequency	72	30	11	9	8
Percent	55	23	8	7	6

Figure 37: Time taken for equipment to be installed for used.

6.2.21. ERP System Usability

The results for this question depict the rating of the respondents on the usability of the ERP System. The scale is from 1 to 5 with one as least user-friendly and 5 as most user-friendly.

Table 17 and Figure 38 show that the rating of the usability of the ERP System by the respondents centred between 3 and 4. This is further described by the descriptive statistics. Table 18 show that the mean rating of the usability of the system is 3.52 on a scale of 1-5 with a standard deviation of 1.228 and variance of 1.507. The sum of the scores from all respondents is 458. The highest possible combined score that can be attained for the sample is 650 (5 x 130 respondents). On a 1-100% scale this is 70.5 %. This means that there is a need to develop further interventions on the system such as trainings and user interface improvements.

Table 17: Usability of the ERP System

Rating Scale	Frequency of Respondents
1	10
2	16
3	35
4	34
5	35
Total	130

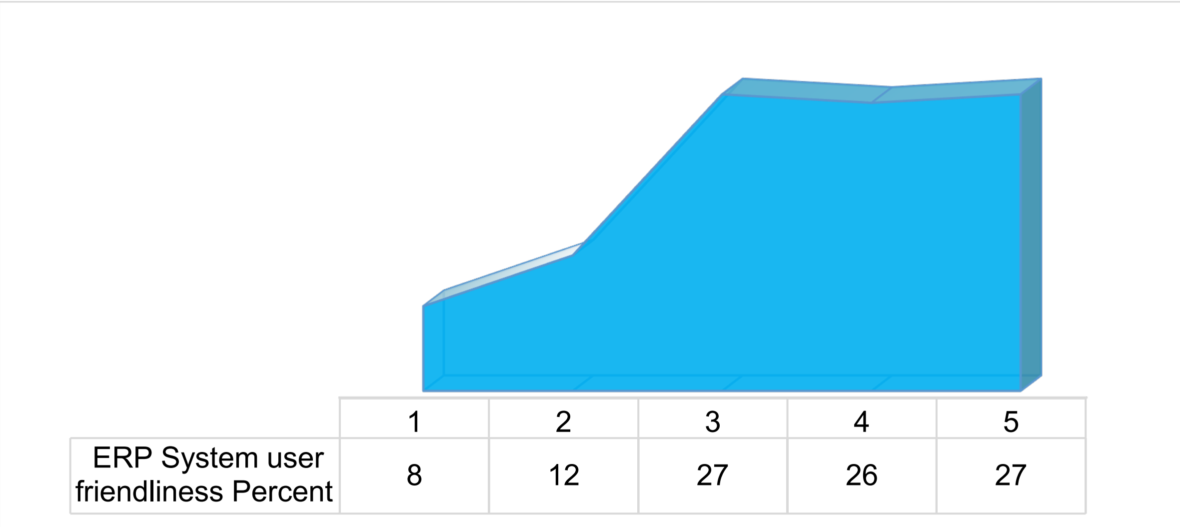


Figure 38: Graphical representation of Usability results

Table 18: Descriptive Statistics for the usability of the ERP System

Mean	3.52
Median	4.00
Mode	3^a
Std. Deviation	1.228
Variance	1.507
Skewness	-0.450
Std. Error of Skewness	0.212
Kurtosis	-0.704
Std. Error of Kurtosis	0.422
Range	4
Sum	458

6.3. Case Study Review Analysis

In order to collect data related to the current landscape of implementations of Lean management and Industry 4.0, the researcher surveyed and developed analysis from the peer reviewed journal articles. A table was developed to summarize the case studies, implementation techniques, concepts and the possible adaptations to the problems identified during the survey part of the study.

6.3.1. Analysis of Lean Management Case Studies

This section relates to the sub-question on Lean Management its applications in supply chain improvement. The sub-question is:

How can lean management be implemented to minimize delays supply chain processes?

6.3.1.1. Lean Six Sigma, DMAIC and VSM Case Studies

Table 19: Case studies where lean six sigma, DMAIC and VSM were used.

Title	Author	Synopsis	Potential Application to Current Study
Using Six Sigma DMAIC to improve the quality of the production process: a case study.	[148]	The study used the DMAIC (Define-Measure-Analyse-Improve-Control) to identify problems with the production cycle of the company. They measured the historical data for the efficiency of the production machine. Using brainstorming, they analysed the data and classified it into categories of work, method, man and machine. They then implemented the Single Minute Exchange of Dies (SMED) to reduce the downtime of the machine during changeovers. The control phase is to audit the changes implemented in the process and its impact and review changes continuously.	The survey has shown many gaps in the procurement process. The DMAIC process can be applied in the procurement process to develop solutions on the category B issues (time taken to complete processes)
How to use lean manufacturing for improving a Healthcare logistics performance	[149]	This study used VSM and DMAIC with DMAIC to reduce the order processing time	

Bottleneck Identification and Process Improvement by Lean Six Sigma DMAIC Methodology.	[150]	The study used Six Sigma DMAIC in a food processing company to reduce bottlenecks and non-conformance in production and packaging processes. In the define phase, the study used SIPOC (Supplier Input Process Output Customer) to identify the problems. For the measure phase, they utilised VSM (Value Stream Mapping) to indicated nonvalue adding activities. In the analyses phase, they used statistics using one way ANOVA statistics. In the improve phase, the causes of bottlenecks were identified using Ishikawa diagram (cause and effect diagram) and devising an action plan. They identified strategies in the control phase continuously improve the process.	The survey has shown many gaps in the procurement process. The DMAIC process can be applied in the procurement process to develop solutions on the category B issues (time taken to complete processes)
An Optimisation Framework for Improving Supply Chain Performance: Case study of a bespoke service provider	[151]	The study validates an optimization framework for improving service supply chain performance using DMAIC cycle. They used a bespoke service provider was used to test the applicability of the framework. This included identifying KPIs for different supply chain elements and links. This study contributed to the current research by developing a performance optimization framework for service supply chain using DMAIC cycle.	KPI's and Framework

6.3.1.2. Analysis Related To Lean Office Tools

Case Study 5

Title: Processes improvement applying Lean Office tools in a logistic department of a car multimedia components company.

Author: [152]

Synopsis

The study used Lean Office tools and a Technique called Action-Research by analysing existing logistics department processes. The methodology as described by [153], include 5 stages: 1) Diagnosis; 2) Planning actions; 3) Implementation; 4) Evaluation and discussion of results; 5). The study achieved its objectives by reducing wastage, achieving transparency, clear identification of tasks and responsibilities of each employee.

Concepts to be adopted in current research study.

Role and task identification and allocation for the procurement team

6.3.2. Studies on Industry 4.0 initiatives

This section relates to the sub-question on Industry 4.0 and its applications in supply chain improvement.

How can Industry 4.0 initiatives be implemented to advance efficiency in supply chain processes?

6.3.2.1. 3D Printing

Table 20: Case Studies on 3D Printing

Title	Author	Synopsis	Potential Application
Effect of 3D printing on supply chain management	[154]	The study looks at the use of 3D printing or additive manufacturing and its impact on supply chain management. It emphasises the importance of suppliers using it for manufacturing components to reduce lead time by using fewer materials, less assembly steps. The study further denotes that AM has been used in industrial products, specialised equipment and others. This can definitely be used in this procurement process in order to fast track the long lead time identified by the survey. Streamlining the manufacturing process is a benefit in adopting the 3D printing of parts for the research equipment.	Establishment of 3D printing facilities that will deal with sudden growth of demand. This will ease pressure on the procurement process and reduce costs of manufacturing if this is done internally.
Hybrid simulation models for spare parts supply chain considering 3D printing capabilities	[155]	The study focuses on the use of 3D printing in manufacturing spare parts by the United States Navy. The use of models for forecasting of the demand for the spare parts is a key part of the functioning of this Industry 4.0 enabler. The simulation model uses agent based, and discrete events to mimic the practical supply chain of spare parts[155]. The key take in this study is the use of the 3D manufacturing facilities to manufacture spare parts on demand, thus reducing the risk of stock outs. In the procurement process of the university being studied, having 3D printing facilities will assist in ensuring adequate inventory, even with a sudden growth of demand.	

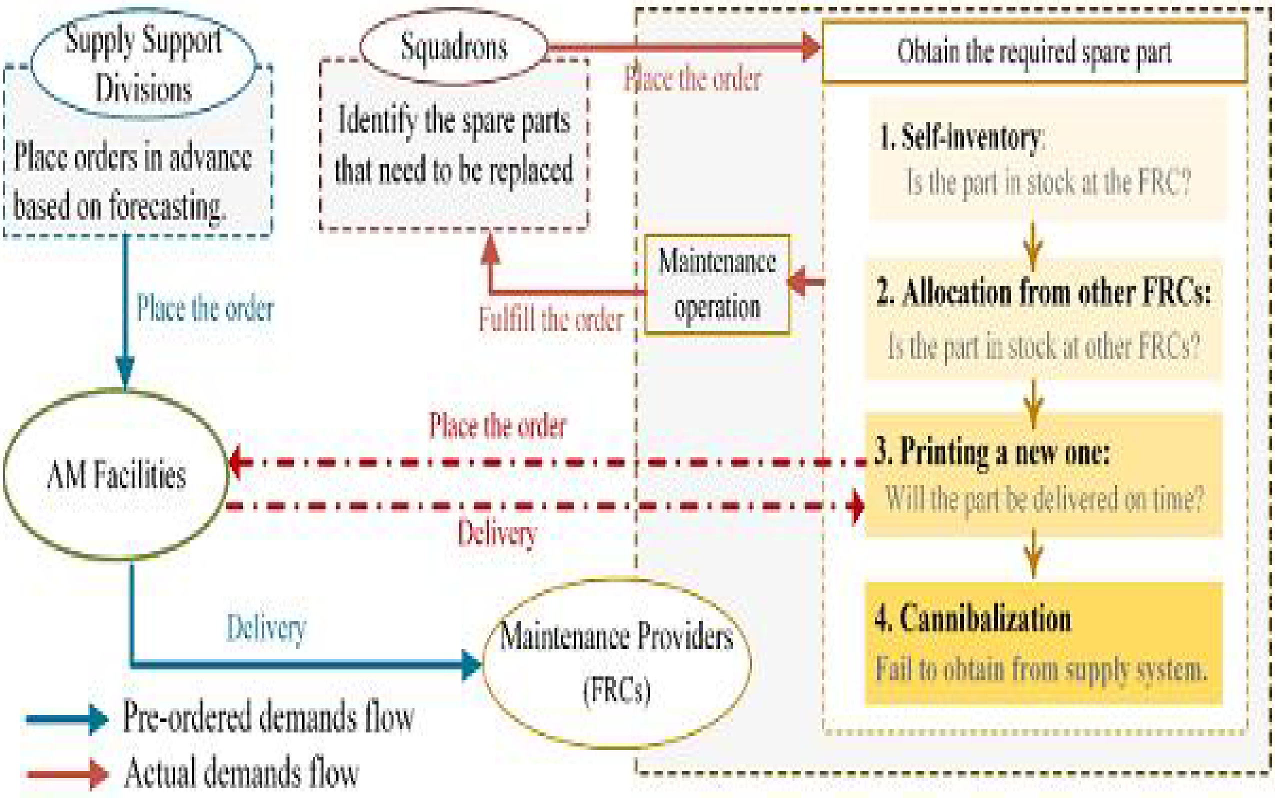


Figure 39: Flowchart of the U.S. Navy's Spare Parts Operations.

Source: [155]

6.3.2.2. Artificial Intelligence (AI)

Title	Author	Synopsis	Potential Application to Current Study
AI in Supply & Procurement	[156]	The use of Artificial Intelligence elements in supply chains is discussed by the authors. Block Chain, which is an element of AI, can be used to track and trace the digital footprint of a product or part from the primary producer to any party involved in the value chain[156]. The use of programmatic buying has made the initially complex procurement processes to be instantaneous by using the analysis complex combinations of data, online veritable data, stakeholders and machine learning systems[156]. The authors endorse the improvement of the skillset of professionals in the IT support systems and procurement. This skillset would be related to data & AI science.	The use of artificial intelligence models to accurately forecast the demand of frequently ordered items such as computers, mass research items. The instantaneous nature of the elements of AI such as block chain and basic forecasting models presents a good opportunity for the institution to plan for adequate inventory levels. It also presents with an opportunity for a university to have a niche research area of AI in supply chains.
Application of Artificial Intelligence to optimize forecasting capability in procurement	[157]	The paper emphasize the extent Artificial Intelligence can be used for improving the demand forecast accuracy in supply chains. The authors further compare AI models with traditional statistical models that are static. The AI models in the study performed better in determining the accurate and up to date forecast.	

6.3.2.3. Augmented Reality (AR)

Title	**Author**	**Synopsis**	**Potential Application to Current Study**
Augmented Reality in Warehouse Operations: Opportunities and Barriers	[158]	This paper discusses the benefits from using AR in distribution centres. The authors experimented with the use of Google Glass (wearable technology) for various warehouse operations such as picking, shipping and packing. Among others, the benefits were reduced error rate, expanded operator flexibility without using handheld scanners, improved picking accuracy and Avoiding unnecessary movements [158].	The use of AR and VR can be used to visualise the product and correct specifications of items can be clarified before the product is manufactured or delivered to the researchers at the institution. In this way, the research equipment is correctly delivered and installed quicker, thus enabling a productive research process.
AR/VR Technologies And Their Applications In Procurement	[159]	The paper evaluates various literature around the use of Virtual Reality and Augmented Reality in the procurement environment. The overall benefits in the summary of literature simplification and clarification of requisition documents, elimination of defected product purchase, proper elucidation of customer needs (Krasyuk & Fedyakov, 2020).	

6.3.2.4. Big Data

Title	Author	Synopsis	Potential Application to Current Study
Industry 4.0 sustainable supply chains: An application of an IoT enabled scrap metal management solution	[160]	The paper looks at the application of IoT in the scrap metal and waste management processes. The study proposes a real-world application of IoT in supply chain. The shop-floor bins were fitted with IoT sensors, real time monitoring for fill levels, data visual system for optimization of planning tasks as well as an online bidding (price negotiations for scrap dealers and waste management companies). The model is further depicted in Figure 40.	An online bidding system for price negotiation can be used by the initiators of requisitions and suppliers for faster quotation process.
Big Data Driven Supply Chain Management and Business Administration	[161]	The authors review Big Data applications in supply chain management, its applications and pitfalls in achievement of business objectives. They further elaborate on how Big Data application can assist in the elements of a supply chain i.e., better forecasting by demand and supply chain planning, location tracking using RFID. Incorrect data or "dirty data" coupled with data privacy policies preventing full sharing can be a major challenge toward optimal	RFID Tags to monitor stock and demand forecasting of research equipment that is frequently utilized by the staff. This will inform the assets and warehouse team to trigger an automatic request for stock requisition as to avoid stock outs.

		implementation and use of Big Data for business objectives	
Big data analytics for supply chain relationship in banking	[162]	In this study the authors use big data to analyse supply chain relations for credit reports and e-wiring transactions for its Business to Business (B2B) partners. The study further portray how can big data analysis can provide solutions for the marketing campaigns and risk management.	A risk mitigation strategy can be derived from the Big data analysis for frequently utilized suppliers.
Supply Chain Risk Management in the Era of Big Data.	[163]	This paper provides a novel framework that uses Big Data to develop an effective supply chain risk management system for stochastic environments.	

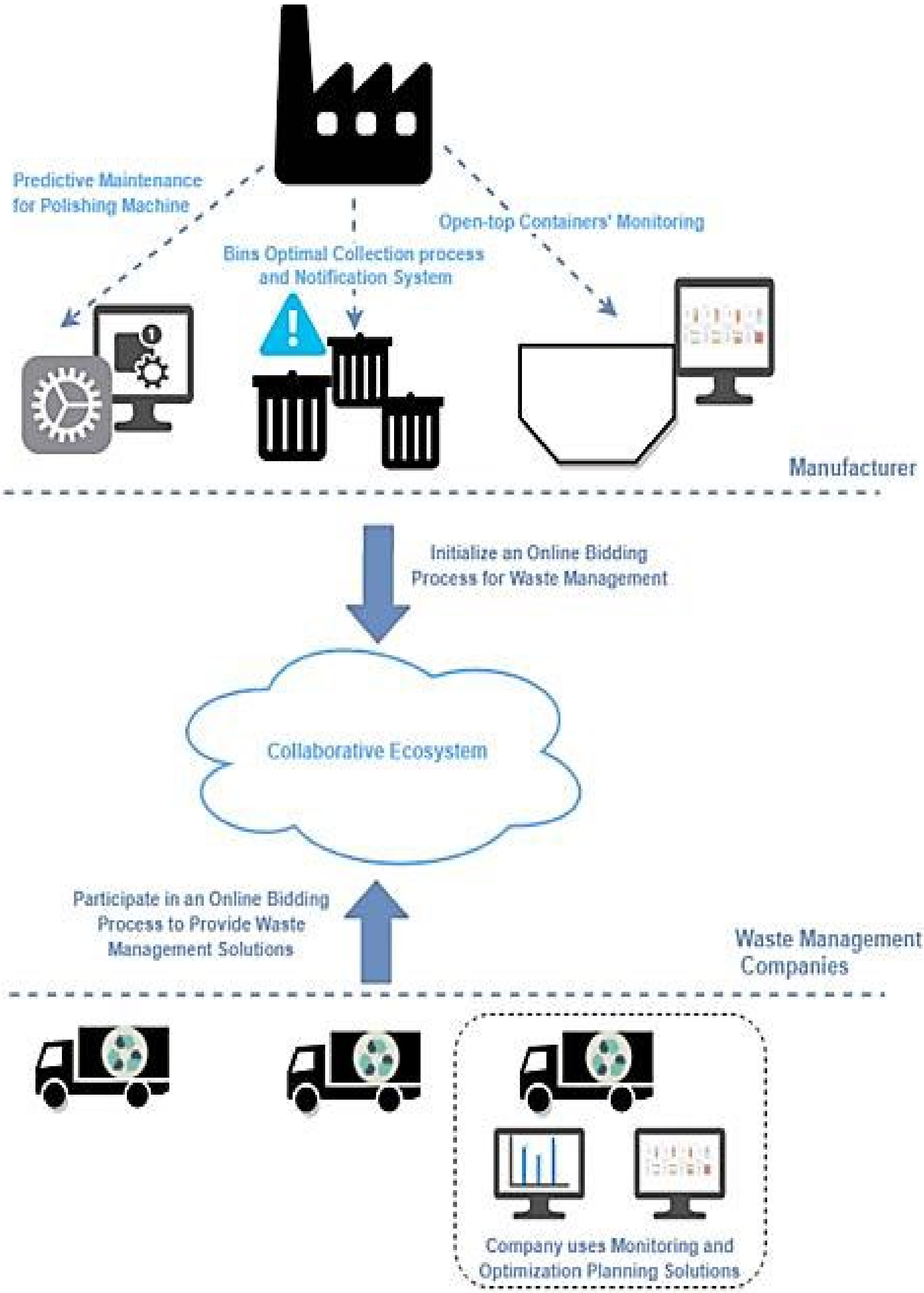


Figure 40: High Level architecture of solution proposed by Source: [160].

6.3.2.5. Cloud Computing

Title	Author	Synopsis	Potential Application to Current Study
Cloud computing procurement and implementation: Lessons learnt from a United Kingdom case study	[164]	In this case study, Cloud Computing was deployed to reduce procurement costs and advance political ambitions of implementing CC by the government. The grounded theory was used for the qualitative research (interviews with staff) [164]. After triangulation of the responses, it was evident that the implementation of cloud computing was successful and yielded benefits such as increased resilience, sharing of resources and improved agility. This implementation also mitigated risks such as Poor performance and Service unavailability.	A model to map and measure CO2 emissions by the procurement process of research equipment to assist the university with its gas emissions target.
Cloud computing technology: Reducing carbon footprint in beef supply chain	[165]	In this case study, cloud computing was used to integrate the segregated segments of a beef supply chain with an aim to reduce the carbon emissions throughout the value chain[165]. In this pilot study, the model identifies the carbon hotpots in the value chain e.g., farm, logistics, slaughterhouse, processor and retailer and its associated carbon footprint. From the analysis screen, they can measure the carbon footprint and locate the improvement areas.	

6.3.2.6. Internet of Things (IoT)

Title	Author	Synopsis	Potential Application to Current Study
Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems	[91]	This research paper presents the use of Internet of Things (IOT) framework for supply chain management which based on IOT technologies. The authors propose a system to automate d and address the existing supply chain problems and complexities. Through the use of RFID technology, the flow of products was tracked throughout the value chain. The data obtained was linked to the supplier code and then made available to the store managers as to identify important information about the supplier [91]. The authors further propose a framework that which integrates neutrosophic Decision Making Trial and Evaluation Laboratory (N-DEMATEL) with analytic hierarchy process (AHP) procedures to understand interrelationships for a smart supply chain.	An online system that can be used by the initiators requisition and procurement team of to understand the supplier lead times, historical delays and other related information before making a selection for service or product provision.
Data Analytics Using IOT In Procurement	[166]	In this paper, Mulay [166] proposes a model of implementing a smart eProcurement from a manual system. The authors suggest computerization of the procurement process using sensors in products. These sensors would learn the insights on product utilization frequency embedded on the item master data. The sensor would then raise an automatic purchase requisition and purchase order. The author summarises by stating that “This learns from the dataset provided, analyse, draw insights and take intelligent decisions”[166].	Coupled with the sensor use promulgated by [166], this can be an automated system using IOT analytics. This can follow a model proposed by Mulay [166] in Figure 41.

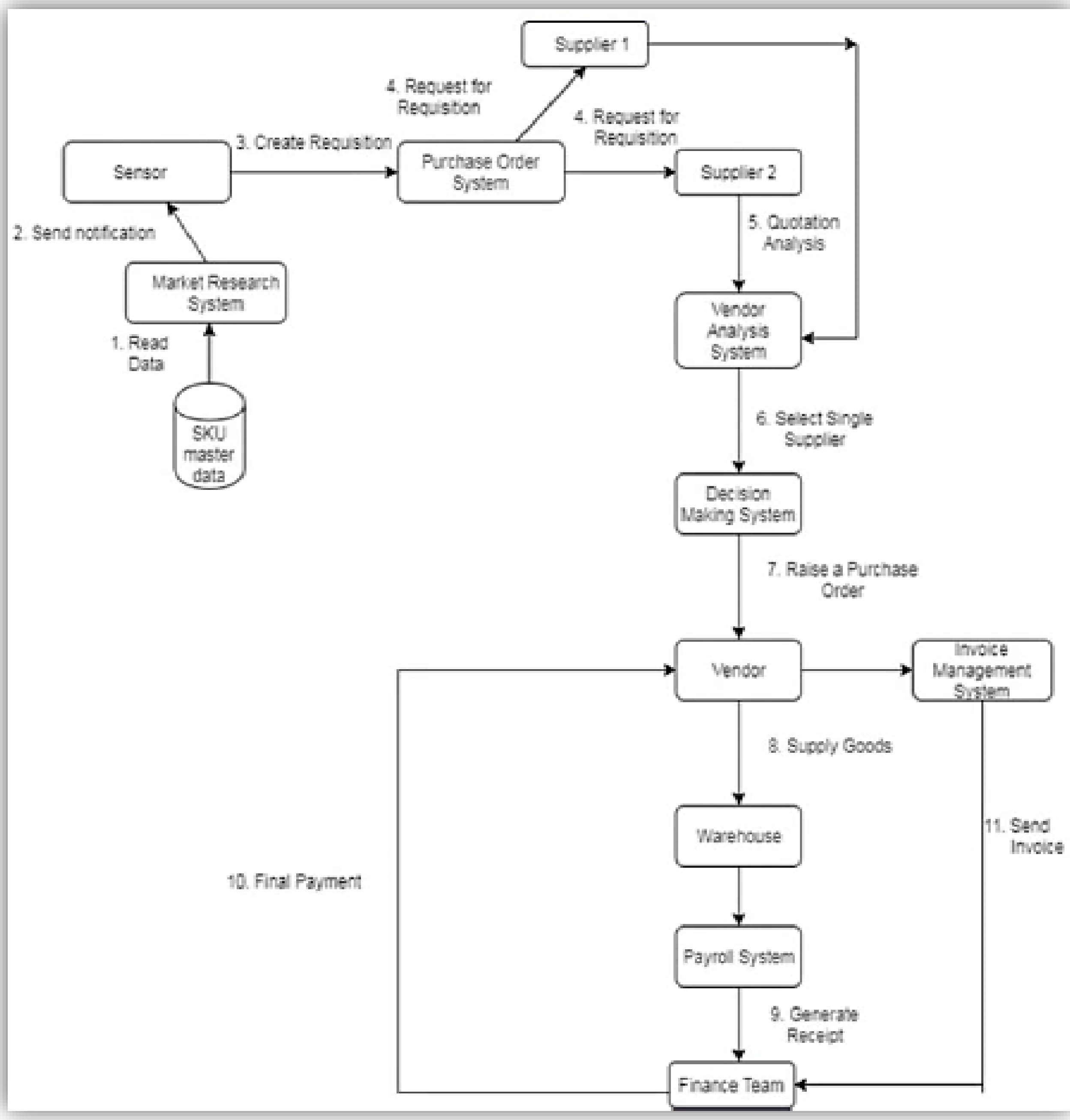


Figure 41: Procure-To-Pay model implementation for IOT in procurement.

Source: [166]

6.3.2.7. Omni Channel

Title	Author	Synopsis	Potential Application to Current Study
Showcasing optimization in omnichannel retailing	[167]	In this paper, the authors propose a generalised model for optimization that can be used in various productions. The model is focused on high-value products [167]. This fits perfectly with the current study as some research equipment are customised and high value products. From this model, a virtual showroom showing with big screens to assist with convening the product features so that consumers can visualize how the product will perform in reality, while saving a large percentage of investment on a physical showroom.	The omnichannel capability can be linked to the ERP system and suppliers of high value research equipment. This could allow virtual viewing rooms that the researchers and buyers (procurement team) can utilize to view functioning and suitability of the equipment before buying it.
The effects of BOPS implementation under different pricing strategies in omnichannel retailing	[168]	The authors profile the BOPS (buy online and pick up in store) system in different pricing strategies of omnichannel. The model and test used imply that there are significant savings that the consumer can realize by utilising this route of BOPS.	The BOPS capability can be integrated on the procurement process and system to reduce lead times and delivery delays experience by the participants in the survey of this study.

6.3.2.8. Radio Frequency Identification Technology (RFID)

<table>
<tr><th>Title</th><th>Author</th><th>Synopsis</th><th>Potential Application to Current Study</th></tr>
<tr><td>A new asset tracking architecture integrating RFID, Bluetooth Low Energy tags and ad hoc smartphone applications</td><td>[169]</td><td>The authors explore the use of RFID and Bluetooth tags within the construction sites. They integrated with the tags and smartphone applications through android applications for the search and track function [169].</td><td rowspan="2">The use of smart tags with RFID can be explored by the asset management department for tracking and can be integrated with app-based tracking. The architecture proposed by Bisio et al. [169] in Figure 42 is practical and can be adapted to this study. The adaptation of the steps of evaluation of the implementation of RFID is critical and Dovere et al. [170] provides the steps as depicted in Figure 43.</td></tr>
<tr><td>An assessment model for the implementation of RFID in tool management</td><td>[170]</td><td>In this paper, the authors [170] offer an experiential model to gauge evaluating the cost benefits when implementing RFID use for identification.</td></tr>
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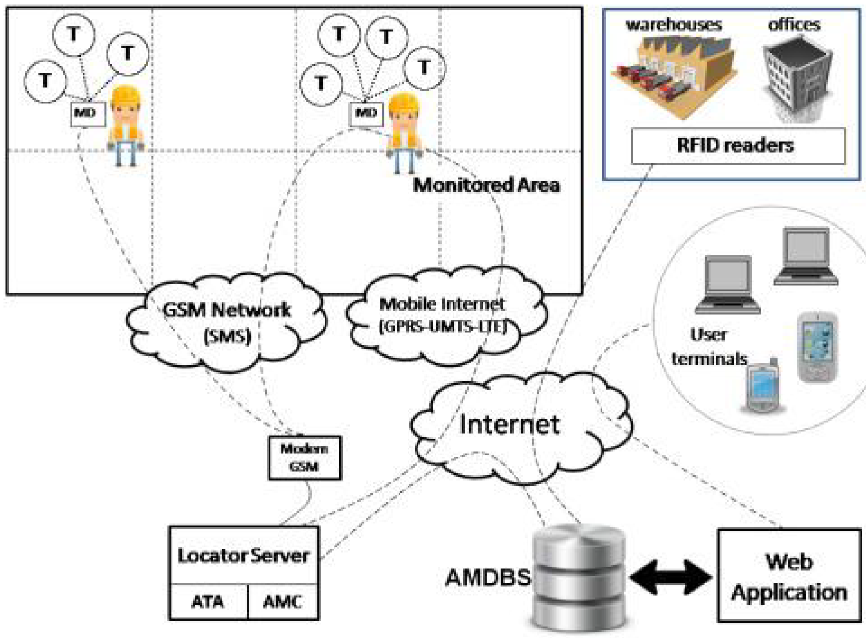

Figure 42: An example of architecture proposed asset tracking scheme

Source: [169]

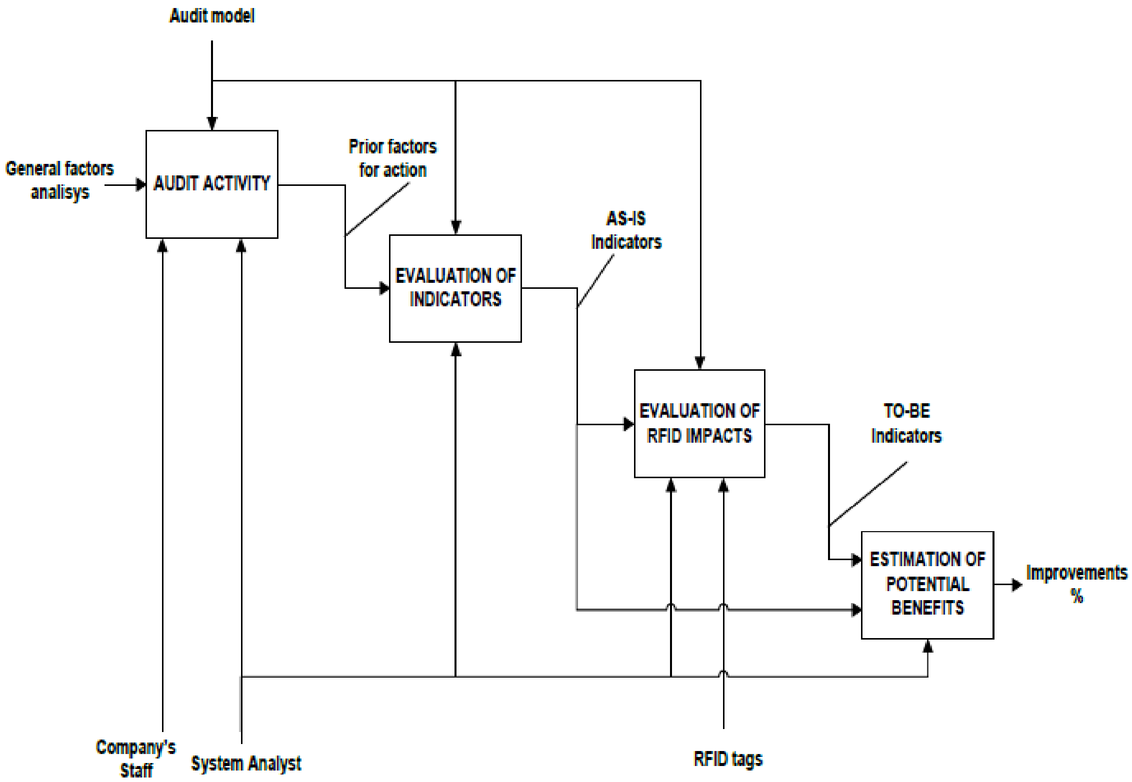

Figure 43: Main steps of application of the assessment model for RFID

Source: [170]

6.3.2.9. Robotics

Title	Author	Synopsis	Potential Application to Current Study
Tortoise, not the hare: Digital transformation of supply chain business processes	[171]	In this paper the authors analyse the digital transformation of supply chain processes. They explore the quick wins that Robotic Process Automation (RPA) can achieve for routine processes. Lowes et al. [172] further state that the RPA tasks include data entry, simple mathematics, processing of data from ERP systems and filling of forms. The use of RPA software is recommended by the authors for automation of these tasks.	Integration of RPA software into the ERP system of the university for automation of tasks like creation and processing of purchase orders and invoice preparation
Automation in procurement: Your new workforce is here	[173]	KPMG company is a well-known global consulting entity and develops solutions for many companies. For the purposes of this study, the application of bots in procurement is chosen as an example. The company has implemented over 600 bots in various industries and in processes such as customer support, purchase order conversion.	Integration of chat bots in the ERP System, for the purchase requisition initiators for proper track and tracking and effective communication with the procurement team.

6.3.3. Sensor Technology

Title	Author	Synopsis	Potential Application to Current Study
Using smart sensors to drive supply chain innovation	[174]	The authors profile the applications that companies that have integrated smart sensors into manufacturing operations and asset management for tracking real times status of items [174].	The smart sensors can be explored as a method to assist asset management to fast track their processes by allocating a sensor before the tagging and asset registration. This will then trigger the phone application to remind the asset registration team to follow up and complete item registration within time.
Adoption of the Internet of Things technologies in business procurement: impact on organisational buying behaviour	[175]	The authors look at the application of IoT technologies in procurement. Technologies such as sensors and chips are stated as future tools for information gathering which may replace research surveys, supplier visits and equipment tests [175]. With embedded chips, sensors and communications technologies, little funds will be spent on the traditional methods of data collection.	For computer items, the current repair processes take longer to complete as they have to be sent to the suppliers because of warranty. Collaboration with the manufacturers in sharing diagnostic data with the IT department so that the repairs can be done at the in-house workshop.

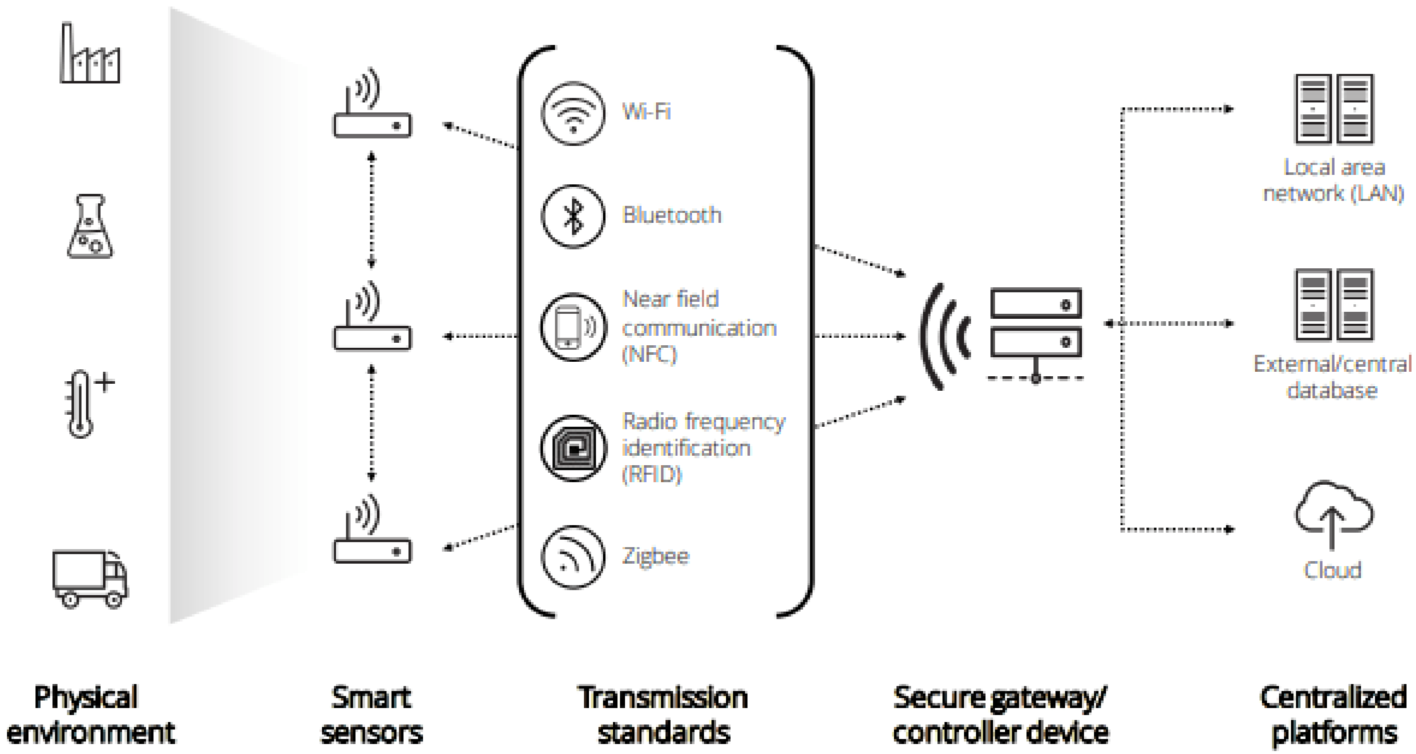

Figure 44: The smart sensor ecosystem

Source: [174]

6.3.4. Simulation

Title	Author	Synopsis	Potential Application to Current Study
A Simulation Based Approach to Investigate the Procurement Process and Its Effect on the Performance of Supply Chains	[176]	The paper suggests the simulation of different procurement strategies and different manufacturing scenarios. This is done to easily analyse and choose cost efficient procurement strategy without practically testing the actual strategies [176]. The simulations of supply chains are used in order to improve the production process. In this study they use simulation to test the factors impacting on the supply chain's performance.	From both studies in this simulation section, the models can be developed to imitate various scenarios. The results from the simulation studies can inform the procurement team to develop risk management strategies for extreme events that can disrupt the supply chain system. Furthermore, contracts renewal scenarios can be simulated to further inform decision makers.
Gamifying Project Procurement for Better Goal Incorporation	[177]	The authors suggest using a participatory simulation for investigation of different issues existing in road construction procurement and its complexities. They use the simulation to restructure procurement agreements based on different life cycle instances.	

6.4. Chapter Summary

This chapter is dedicated to the results of the survey that was sent to the respondents as to ascertain the efficiency attributes of the procurement process for research equipment. The demographics of the participants are discussed with subheadings of participant type (administration staff, student and researcher), gender, race and faculty. The results from satisfaction related questions are presented ranging from the responsiveness of the procurement team, satisfaction with requisition approval time, satisfaction with order processing time, order accuracy, supplier payment delays and satisfaction with ERP system. The results on efficiency related questions are on requisition preparation time, requisition approval time, order entry time on the system after approval, time taken to release purchase order to supplier, product or service processing time by supplier, supplier delivery time, asset registration and installation.

This chapter also presents the results from the analysis of case studies where lean management and Industry 4.0 applications have been implemented. This forms a fundamental background of the formulation of recommendations for improving the efficiencies and continuous improvement to be used in this research study for the procurement process for research equipment. The reviewed case studies were mainly related to supply chain area, specifically the procurement component.

For lean management, the practical and peer reviewed papers focused on lean six sigma, DMAIC, value stream mapping and lean office tools. These case studies provide a crucial basis for formulation of lean related solutions and recommendations as well as the finer details of implementation. The practical implementation of case studies related industry 4.0 enablers was done using peer-reviewed journal articles. They focused on practical applications and implementation of 3D printing, artificial intelligence (AI), augmented reality (AR) and virtual reality (VR), big data, cloud computing, internet of things (IoT) applications, omni-channel, radio frequency identification technology (RFID, robotics, sensor technology and simulation.

7. CHAPTER SEVEN: RECOMMENDATIONS

7.1. Introduction

This chapter focuses on the recommendations that are solutions grounded on lean management and Industry 4.0 to improve supply chain efficiency in an integrative manner, and address the issues unearthed by the survey.

7.2. Acquaintance with the Procurement Team

In Chapter 6, it was discussed that 47.7% of the respondents knew the procurement team and structure while 14.6% were not sure if they knew the procurement team and structure. The remaining 37.7% did not know the procurement team and who to contact for purchase order tracking and other queries. This is a large percentage and solutions need to be developed to address this point.

This is a “low hanging fruit” opportunity for the procurement team to improve its efficiency by being visible and know to the end users. Currently this is achieved through an organogram of 11 PowerPoint Slides describing existing “finance and procurement” structure. To improve this, a flowchart with tasks, people, responsibilities and contact methods can be developed.

The flowchart of the procurement organisation can be published in the welcome pack for 1st year doctoral students that is issued digitally. In this way it can be located easily and utilized during second year of study when the procurement of research equipment commences. The administrative staff and researchers that will be dealing with the procurement of research equipment using the standard university process can be let known of this visual flowchart through the university system intranet and internal portals.

In an organisation, the roles and responsibilities of each person must be clear in order to ensure optimal functioning of work [178]. When the research equipment process flowchart is developed, it must be clear and have pictures and contact information of the people responsible in the whole process chain from when then requisition is originated until the equipment is installed and ready for use. This must include links for the methods that the end-users can utilise to track the progress for the purchase orders.

The frequency of issuing reminders about this flowchart to administrative staff and researchers must be regular. The flowchart must also be available and be visible in the intranet system. The current published document which can be categorised as an organogram was last reviewed in 2012. There has been many resignations, structural re-organisations and innovations such as chatbot technologies. Notably, this must include a process flow for the research equipment or services. Upon completion, the document can then be approved using the university document control procedures and be published.

The university can utilize the in-house institutional planning department and the design studio to create a visually appealing document. This will not cost extra money in the organisation but will be an internal exchange of skills and currency. A proposed example of the flowchart is shown in Figure 45 with the details.

Steps	Process Diagram	Responsible Person	Procurement Contact	Contact Information
1	**Prepare Requisition on the ERP System.** ↓	**Originator**		
2	**Requisition Approval** ↓	**HOD**		**Your Head of Department Details**
3	**Order Entry on the system after approval.** ↓	**Procurement Team Member X**		Telephone number: Chatbot link: Email address:
4	**Budget Approval and coding** ↓	**Finance Officer**		Telephone number: Chatbot link: Email address:
5	**Release of purchase order by procurement to the supplier** ↓	**Procurement Team Member Y**		Telephone number: Chatbot link: Email address:
6	**The supplier manufactures the equipment or prepare service.** ↓	**Procurement Team Member Z**		Telephone number: Chatbot link: Email address:
7	**Delivery of equipment/product or service by the supplier** ↓	**Procurement Team Member AA**		Telephone number: Chatbot link: Email address:
8	**Asset Registration by using the Purchase Order and Delivery Note** ↓	**Asset Registration Team Member X**		Telephone number: Chatbot link: Email address:

Figure 45: Proposed Visibility Flowchart

7.3. Responsiveness

Twenty-six percent of the respondents perceived the procurement team as always responsive. This is quite a low percentage, showing that a very low number of process users were found the procurement team always responsive. For mostly responsive, rarely responsive and sometimes responsive options, the percentage were 26.9, 19.2, and 27.7% respectively. In order to show the reflective percentage least satisfied users, the rarely and sometimes responsive categories were combined. As a result, 46.9% of the respondents perceived the procurement team to be sometimes and rarely responsive, thus not very satisfied of their responsiveness. For an organisation to be efficient, one of the critical elements is how it responds to its internal and external customers. Kurniawan et al. [179] states that the procurement of goods and services that limited and regulated will impact organisational effectiveness and therefore, the procurement process must be responsive and anticipative [179]. The fact that 46.9 % of the respondents were not satisfied with the responsiveness of the procurement team is a big indicator that there is a risk of the whole process being effective.

The use of robotics applications such as a chatbot can be used to address this issue. The chatbot will be integrated to the ERP system for the purchase requisition initiators for properly tracking and effective communication with the procurement team. The setup of this chatbot can be rule-based, asking the leading questions such as "enter the purchase order number" or requisition number. The other functions that can be integrated can be security features as ID to confirm that it is the originator of the requisition users. This then links the ERP information and statuses of the items as per update by the procurement team. The flowchart design suggested by Selamat and Windasari [180] in Figure 46 is a typical example that can be followed to model the university's chatbot. The advantage of implementing this Industry 4.0 initiative is that:

- the requisition initiators can track the status of their purchase orders quickly.
- with the COVID19 pandemic forcing staff to work remotely, thus not being able to physically meet, the chatbot can be very effective in bridging the gap of the availability of the procurement team.
- the chatbot can keep the conversations and analysis can be done on the staff or students as to ascertain who needs training about the procurement process for research equipment.

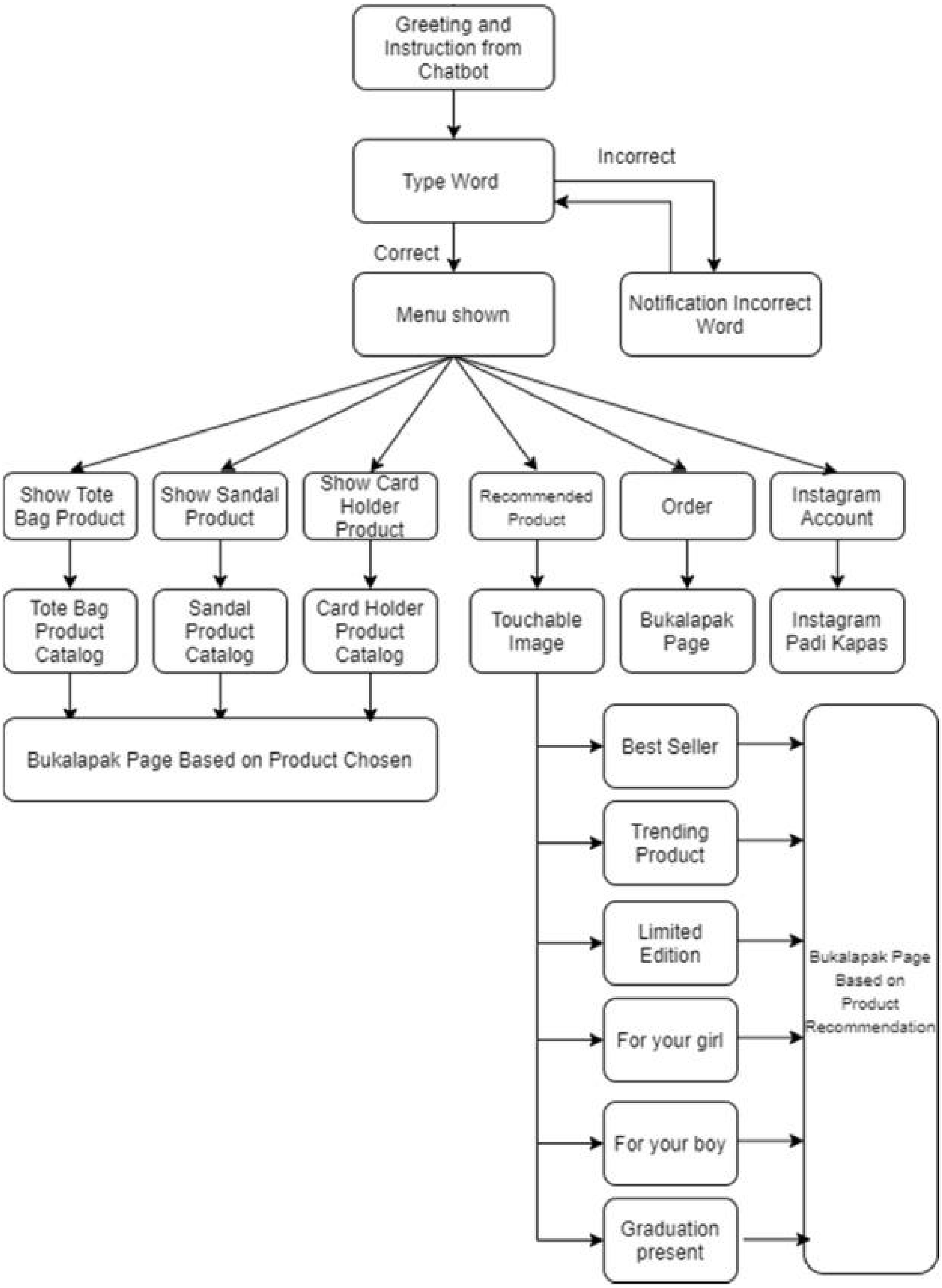

Figure 46: A typical chatbot flowchart design

Source: [180]

Generally, the enterprise resource systems are rigid and robust, thus not really effective in creating notifications that the procurement team can use to live track line items. Normally, the users of the enterprise resource system need to login the system, use a certain module, do operations, and manipulate the data on Microsoft Excel. The businesses usually invest ERP systems that are reliable and available to everybody, a system that will not crash while working (one of the limitations of Excel), thus the robustness and rigidity. The interconnection of chatbot infrastructure onto the university ERP system will need investment into the AI technologies. Then the integration model of Wang 2016, will be applicable for the intra-integration of these Industry 4.0 technologies. The university is currently on Microsoft 365 subscription. This allows an opportunity to negotiate fair pricing with frameworks for building chatbot such as Microsoft Azure.

7.4. Order Accuracy

Since the combined 33.8% of respondents perceived the procurement team to be sometimes and rarely accurate, there needs to be solutions provided to avert this. The right specifications of the equipment, service or product must be achieved. When the order specifications are raised, they are meant to satisfy the needs of the intended results. When the wrong specifications of the research equipment are delivered, there will be issues and that may affect the research process. This is because the research is a meticulous process that needs correct equipment that meets the capacity of certain for proper results.

The use of Augmented Reality and Virtual Reality maybe implemented to visualise the product and correct specifications of items can be clarified before the product is manufactured or delivered to the researchers at the institution. Using Augmented Reality can assist preventing the incorrect material to be ordered by allowing to make decisions grounded on computer generated visualizations and 3D model [181]. In this way, the research equipment is correctly delivered and installed quicker, thus enabling a productive research process.

In terms of the framework, the implementation of this Industry 4.0 initiative in procurement process for order accuracy will be determined by the type of product being procured. For example, buying bulk specialised computers will require horizontal integration as the module for procurement in the university will be linked to the show room of the supplier that uses virtual reality or augmented reality. The staff and students buying the equipment will then have to use the AR module within the ERP System before finalising the requisition form online. After filling the form, then the

ERP system will require the user to confirm that the product specifications and characteristics were confirmed on the AR platform of the supplier.

When buying robotic equipment this AR platform can be used to check the workings before the equipment is ordered. Having this as a requirement in the requisition process eliminated the need for physical travel to the supplier, thereby reducing the cost associated, especially if it was an overseas supplier. The proposed process may follow the idea presented below in Figure 47.

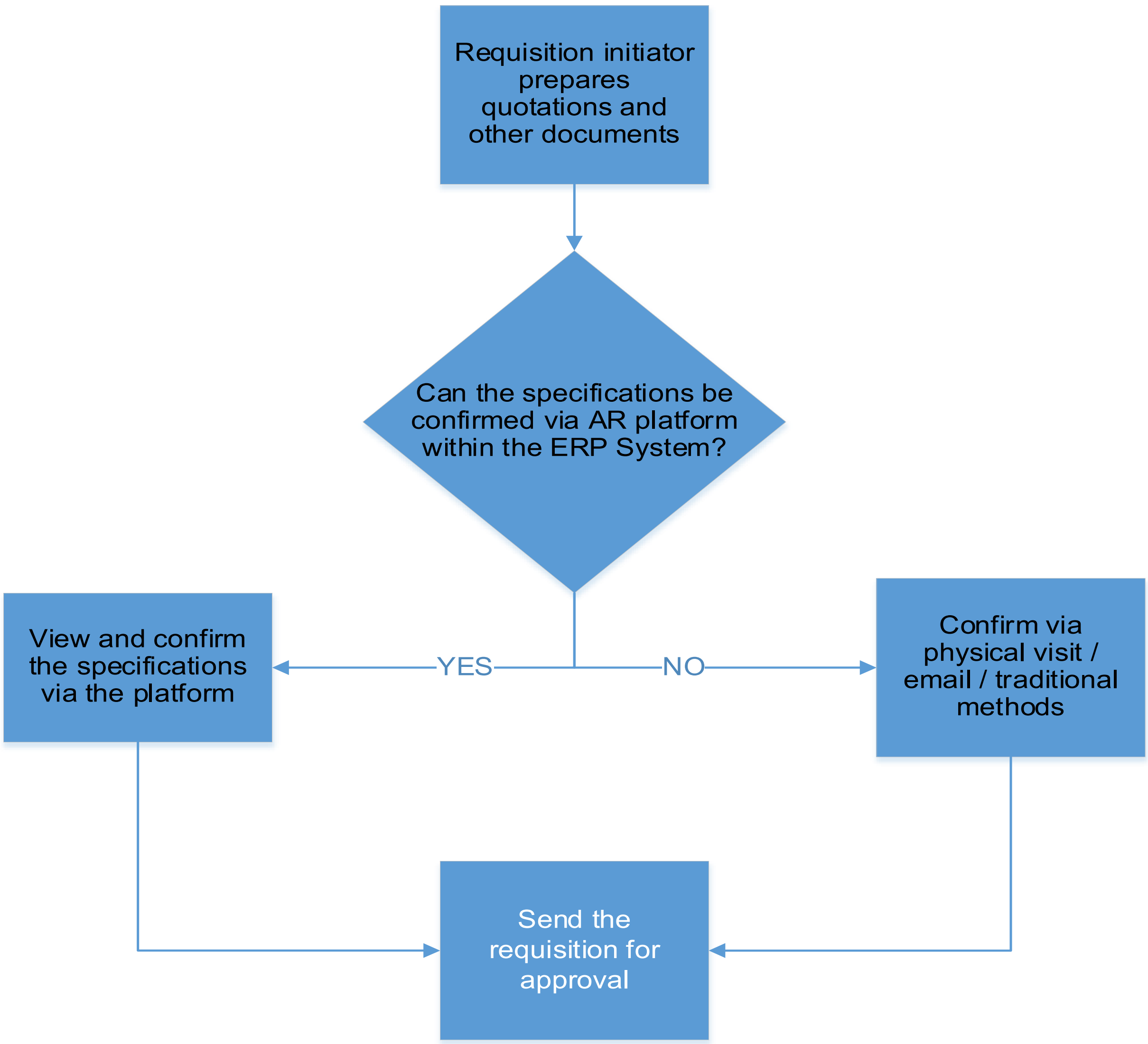

Figure 47: Process flow for product specification confirmation

The confirmation of specifications via the AR platform is essential as an added layer of validating that the precise equipment is bought and delivered so that the delays and inefficiencies in the procurement process are eliminated.

7.5. Satisfaction with Requisition Approval Time

While 75% of the respondents were satisfied with the time taken to approve the requisition by management, a significant 25% were dissatisfied with the time taken to approve the requisition by management. Many factors may have caused this, and the survey revealed that, among others:

- due to covid-19 pandemic, in 2020 most senior managers of the institution were not always available for signatures.
- it took too long to get feedback and had to follow up countless times.
- the requisition was not approved on time, until all the quotations were expired.
- quotations were late from supplier.
- the coordinator was on leave.

It is clear that there are challenges with the current delegation system in Figure 3. A project aimed at streamlining the delegation of authority needs to be further conducted so that there is a clearer process of approvals especially when the managers are on leave and not available to physical approve the requisitions.

The aim of improving this delegation authority system would be to have a clearly defined business approval and legal entity signature for a defined list of decisions throughout the steps of the procurement process. This is necessary to provide a standard yet effective operating procedure throughout the university departments and institutes. Having this system ensures that there is a robust and efficient approvals procedure for all the processes.

In the study by Mncwango et al. [182], the practical use of RASCI is explored in the development of the standard core processes. RASCI is a technique to identify the roles and responsibilities in the process and can be used in an operation or project process, but it must be well-defined beforehand. The incorporation of this method in the improved delegation system may be useful. The RASCI method involves building a grid as explained in Table 21. Using RASCI will assist in task definition in the process, listed vertically in the grid, then all entities or people involved, listed horizontally [182]. This ensures that every task is accurately defined, and every stakeholder understands their role in the process. The envisaged solution should include alternative signatures on the system.

After the definition of the roles using RASCI, this will be digitized and loaded on the ERP system. It will include the procedure for alternative approval in cases where there are delays on the 1st level of approval. The timelines and triggers will be loaded on the system.

Table 21: RASCI Method Explanation

R = Responsible	Person responsible for delivering the task successfully. R are placed under the authority of A. (in this case this is the requisition originator)
A = Accountable	Person with responsibility to approve. (In this case, this is the Management)
S = Supportive	Person supporting the process resources, they are committed to its completion. For this case study, this can be the Finance Team or The Research and Postgraduate Support Unit.
C = Consulted	Person providing valuable information expertise necessary to complete the task. This may be the administrative staff in the departments or the faculty research coordinators
I = Informed	Person providing input and needs to be notified of results but not necessarily contacted

formulated from [183], [184] and [185].

The proposed template for delegation system is presented below in Figure 48.

Steps	(R)esponsible, (A)countable, (S)upport, (C)onsulted, (I)nformed					Research Equipment Procurement Process					
	Initiator	Finance	Procureme	Manage	RPS Office	TASK	Output	Approver	Time taken to approve	Escalation Criteria	Backup Approver
0						Start					
1	R	C	S	A	I	Initiate Requisition	An Approved Requisition	Management	Defined time limit	If allocated time of approval is exceeded and after reminders, without signature, escalate to next level management	2nd level management Member
2											

Figure 48: The proposed template for definition of roles in workflows

7.6. Satisfaction with Order Processing Time

The survey indicated that 75% of the respondents were satisfied with order processing time while 25% were dissatisfied with the tome taken to convert the purchase requisition to purchase order. The respondents stated various areas that are generally lacking on the processing time. These include obtaining three quotes for specialised equipment that can only be produced/supplied only by one organisation.

The recommendation for improvement of the requisition conversion process is to implement key performance indicator tracking. The main indicator to be tracked is the time between capturing of the approved requisition system to when there it is converted to a purchase order. This will assist in flagging the requisitions that have not been converted and creating alerts to the initiators so that they can furnish the procurement team with the outstanding documents such as quotations or specific requirements for the type of requisition mentioned in Figure 4.

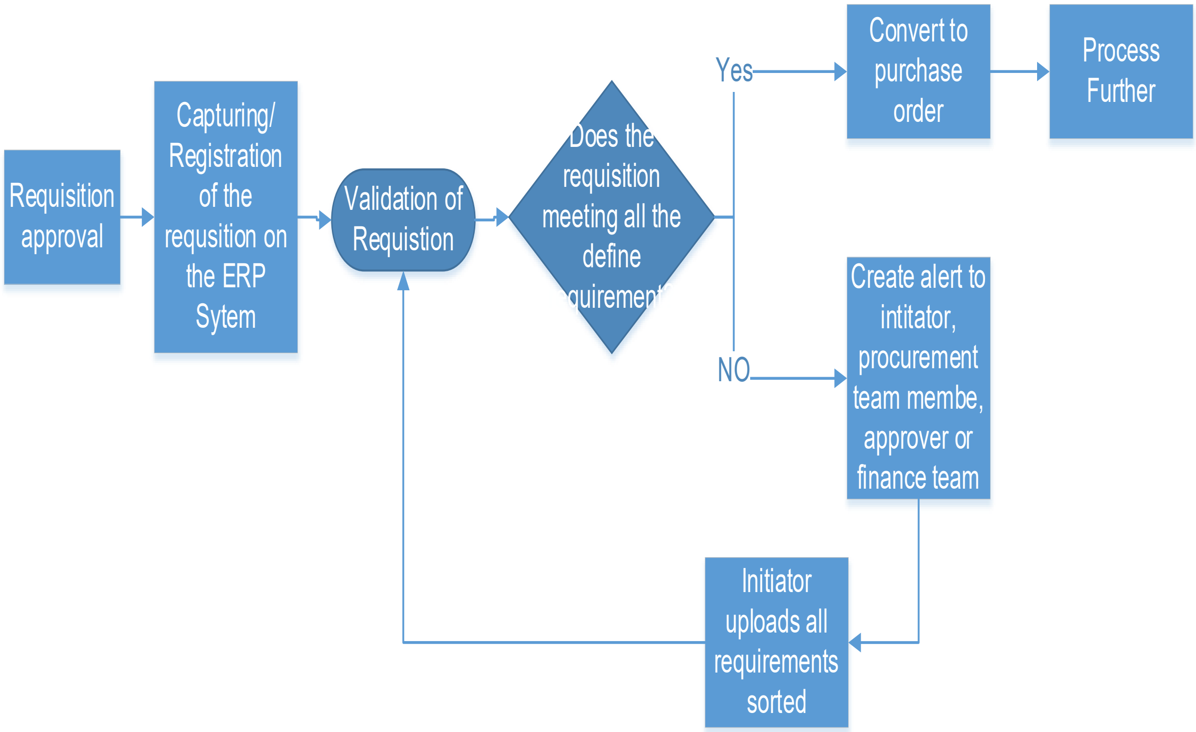

Figure 49: Proposed background flowchart for the conversion of requisition

There are two ways that this can be achieved. The first option is for the procurement team to run weekly reports and track the lagging requisitions. Procurement will then send this to each requisition initiator copied manager to sort out the outstanding requirements. The current ITSS system does not allow the automation of this process (although it does allow workflow), therefore while the university is procuring the new ERP System, this can be an interim measure.

The second option will be viable when the new ERP system is implemented. Workflow management for the conversion will be automatically managed by the system. It will automatically identify the lagging purchase requisitions, the missing requirements, the initiator and manager. It will create an alert that the user can get through a push notification on their email, MS Teams or contact number linked on the ERP System. The time rules will be defined embedded on each requisition type. In this way, an alert is created when the requisition has not been converted after the deadline passes for each order type.

7.7. ERP System – Type of Order Entry

Sixteen percent of the respondents utilized the Hybrid process and 55% used ITSS, while 27% used the manual process. The manual process was used by 27% of the respondents which is a significant percentage and interventions are addressed in the recommendations part. The university has not fully digitised its operations. One of the rules is that requisitions over R10 000, of capital expenditure, building works, repairs and maintenance and research, may not be submitted via the online ordering system. This directly impacts on the research equipment procurement process as it falls into the categories that cannot be done online. The reasons are:

- the legacy of the manual paper system
- need for printed signatures on the requisitions.
- the university does not have a standard digital filing system for supporting the digital procurement system.

The recommendation is to fully digitize the process of procurement to the ITSS enabler for the time being, while the university is in the process of implementing the new ERP system which will enable the expansion of functionalities of the procurement module. Amongst other embedded applications to be implemented, an online bidding system for price negotiation can be built into the procurement module. It will be utilized by the initiators of requisitions and suppliers to enhance and expedite the quotation process.

The use of Robotics Process Automation software that identifies and memorizes patterns and can perform rule-based activities [186]. Embedding the RPA into this ERP system will program several repetitive manual tasks driving efficiency and minimizing errors and risks in implementation [186]. An example will be automatically filling the fields of the digital requisition form. These fields can be identified by using machine learning, and they range from cost centre, budget balance, and automatic identification of requisition type based on total value of order. With the inclusion of machine learning and artificial intelligence, this process can be set to calculate the potential lead time for the certain item. This will manage the expectations of the initiator and they can plan on the research process with more knowledge on when the order will arrive based on the previous or similar orders identified.

The application of this digital procurement will force the university to have improved inputs such as physical quotations, filling system and integrated supplier databases. Daher et al. [186] further stated that implementing the digital and disruptive procurement, will improve organisational and inputs and improved decision making as depicted in Figure 50.

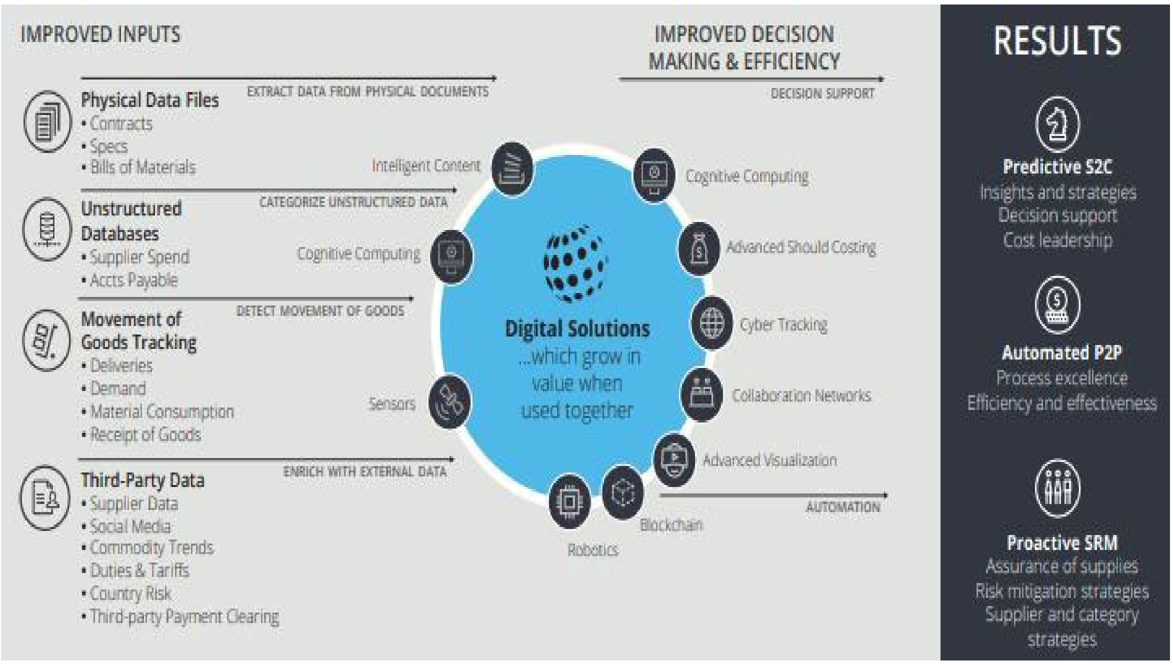

Figure 50: Digital procurement capabilities work together to drive results.

Source: [186]

The improvement of inputs may look into the analysing the various current files such as (contracts or quotations in physical format PDF) which in the current form, hampers the swift access to detailed item information [186]. The item information include pricing, delivery terms and pricing conditions which will be analysed through models to offer advance insights over visualization technology [186].

7.8. Requisition Preparation Time

From the result's analysis 35.4% of the respondents took less than 1 hour to prepare the requisition. The combined 76.2% of the respondents took 0-8 hours to prepare the requisition. The remaining 23.8% took more than eight hours to prepare requisition. This includes obtaining the required number of quotations from suppliers and preparation of summary of quotations form. Obtaining quotations from the suppliers of specialised equipment may be challenging as they are sometimes extremely busy to attend to quotations that they have uncertainty of getting confirmed business. They are aware of the 3 quotations system where the supplier with the lowest quotation is selected. This is due to the need to decrease prices. This is complex because there needs to be a care of not choosing the lowest price but compromising on quality.

One of the challenges that the initiators face is that the supplier does not feel obligated to quote especially if they have monopoly on the research equipment expertise. This is due to that they have a high demand of orders and fulfilling them is critical. They are interested in sure business not potential business that depend on the lowest bidder principle. If a researcher or student wants to buy from this supplier, they have to motivate why they need to select this supplier and deviate from the normal procurement process. This adds more complexity and delays as this has to be approved by the procurement manager and the management according to the delegation of authority before the equipment is the purchase order is passed onto the supplier for fulfilment. Another dynamic is the payment terms as the university uses a standard 30-day payment term. If the supplier wants deposit or cash on delivery, this must be motivated first.

To provide a structured solution for this challenge, a lean management initiative of DMAIC can be used systematically and structurally, to analyse and eliminate all inefficiencies in the process. As described in the literature review section, for this study, DMAIC falls in the Lean Management initiatives. For the purposes of explaining this recommendation works, the researcher will first explain the workings of this initiative, its steps and tools involved. The exploration of Industry 4.0 initiatives will be presented, and the integration methodology will be explained in the context of Wang et al . and Sony models of integration.

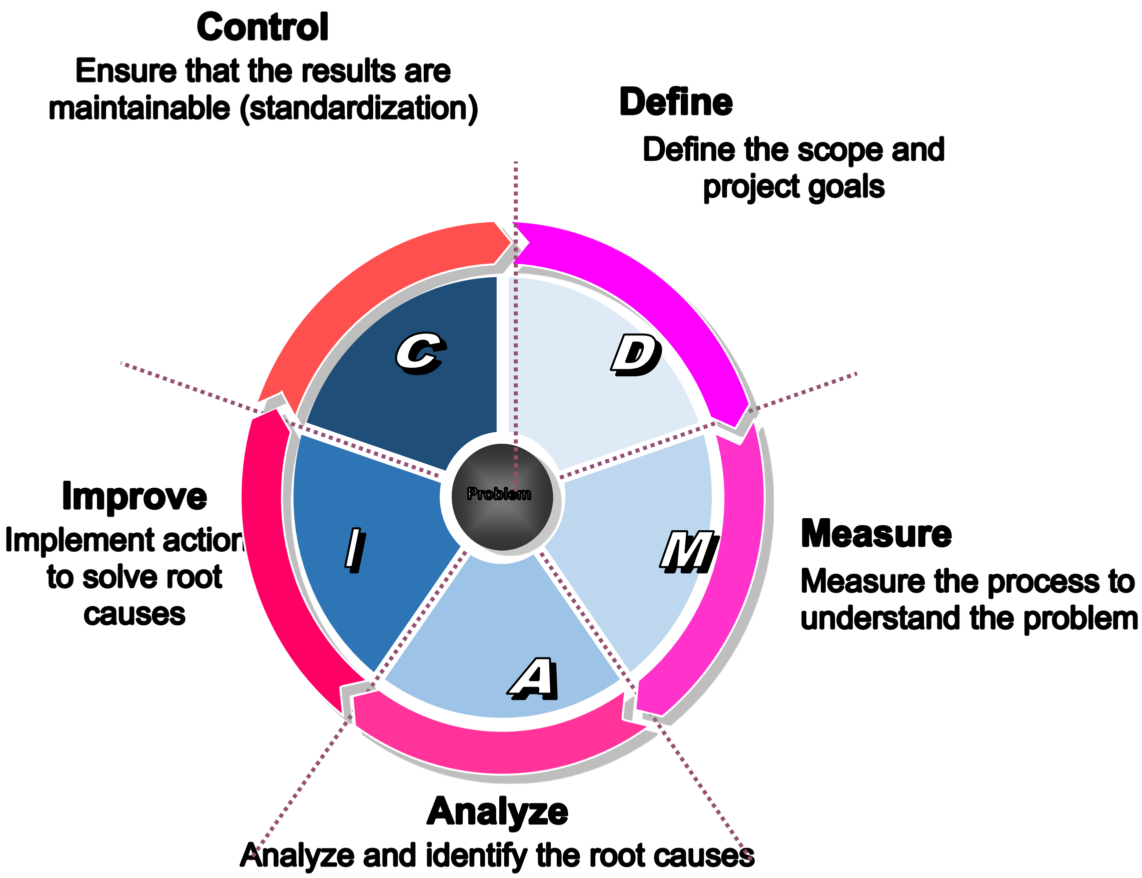

Figure 51: The cycle of the DMAIC problem solving method.

Source: [187]

Using the process in Figure 51, we will further illustrate the basic DMAIC process overview with adaptations for this procurement process.

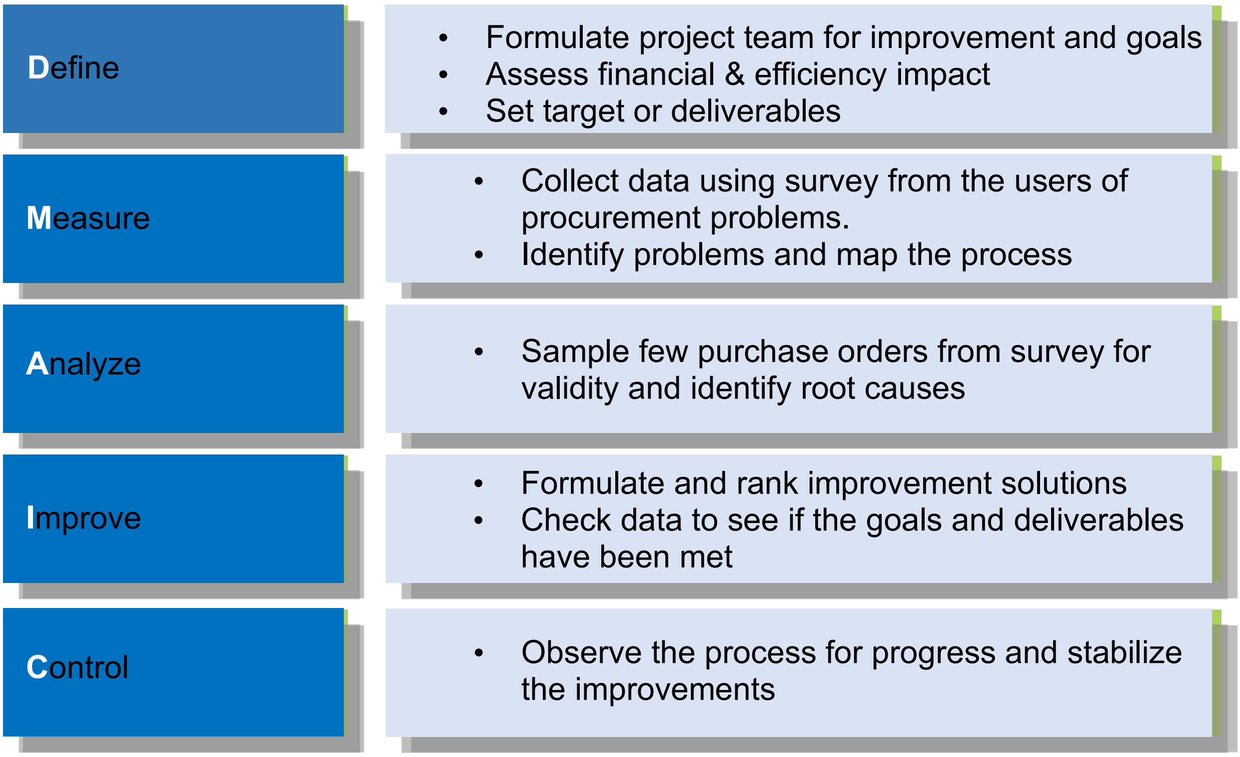

Figure 52: 5 Steps for DMAIC Process

Sources: [188] and [187]

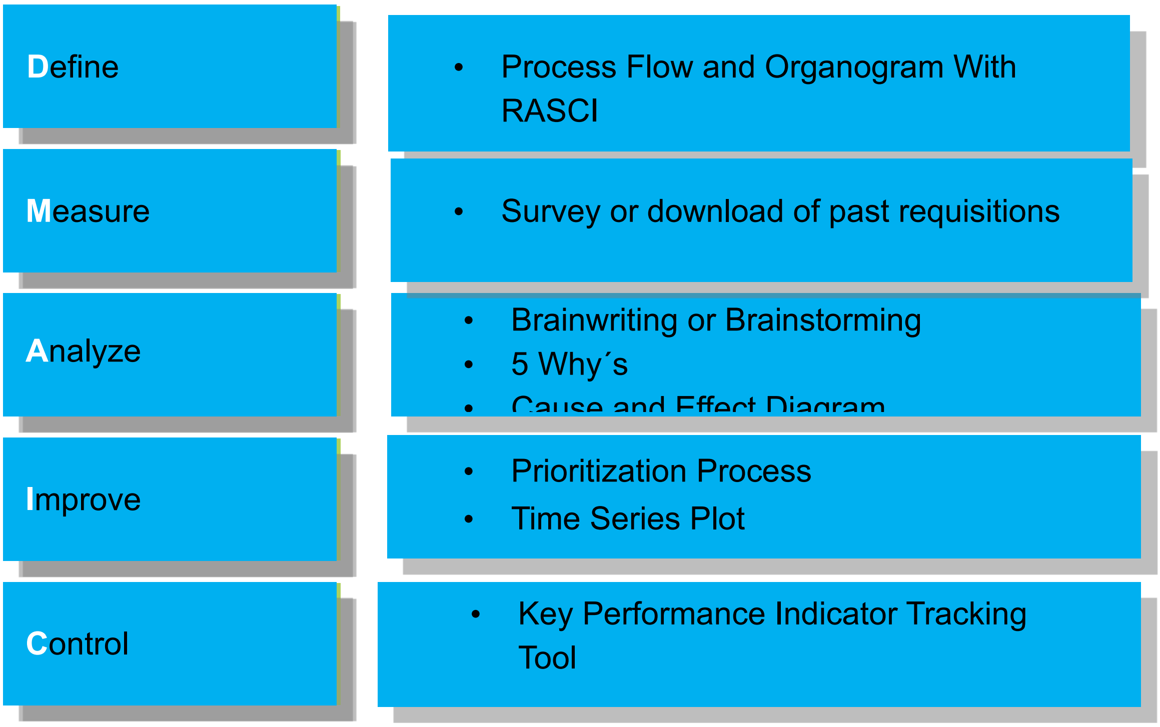

Figure 53: Tools that may be used in each step of DMAIC.

Adapted from [189] , [150], [187] and [188]

In conjunction with the DMAIC method of improving requisition time, the use of Augmented Reality and Virtual Realty applications can be implemented on the ERP system to visualise the product and correct specifications of items can be clarified before the requisition is raised on the system. This will reduce the time taken to request and confirm the correct specifications from the supplier via email.

The integration model to be used for the DMAIC method plus Augmented Reality and Virtual Realty will follow the Lean Management + Horizontal Integration of Industry 4.0. This is because the AR and VR modules on the ERP system will be connected to the external suppliers' systems (for suppliers with available technology).

7.9. Requisition Approval Time

Since the significant 29.2% of the respondents had their requisitions approved after 2 days, there needs to be solutions to address this. These solutions are related to 7.5 which is the satisfaction with requisition approval process. Among other issues experience by the respondents, requisitions were not approved on time due to management being on leave, manual requisitions getting lost during the movements among departments.

The workflow management process and solution envisaged in 7.5 will cover this area with the strong emphasis on time limits definitions that will trigger a push notification through email, Microsoft Teams, and other means such as the WhatsApp or Short Messaging Service (SMS). In Figure 54, the shaded area shows the emphasis on the time trigger components that will be integrated in the ERP system for workflow management of the delegated authority.

Steps	(R)esponsible, (A)countable, (S)upport, (C)onsulted, (I)nformed					Research Equipment Procurement Process					
	Initiator	Finance	Procurement	Manageme	RPS Office	TASK	Output	Approver	Time taken to approve	Escalation Criteria	Backup Approver
0						Start					
1	**R**	**C**	**S**	**A**	**I**	Initiate Requisition	An Approved Requisition	1st Management approval according to the delegated authority	**Defined time limit**	**If allocated time of approval is exceeded and after reminders, without signature, escalate to next level management**	2nd level management Member
2											

Figure 54: The proposed workflow management emphasising time limits

The second component of the recommendation is the implementation of the DMAIC methodology to for continuous improvement of the time taken to approve the requisitions throughout the levels of approvals of the delegated authority. This section will use methodology as in 131 and Lean Management + vertical integration since it involves both lean management and industry 4.0 initiatives implemented on internal organisational systems.

7.10. Order Capture Time on the System After Approval

In order to ascertain the time taken to enter the order in the system after approval by the procurement team, this was the measurement of this aspect of the research equipment process was important in the survey. This time includes the conversion of a requisition to a purchase order and the budget control process by finance officers.

One of the policies of the institution is that the procurement officers may place, and sign orders up to the value of R100 000 and the Head of procurement may sign orders up to the value of R300 000. For orders above R300 000, the Procurement and Materials Manager signs before the order is captured. Over and above that, for purchases between R20 000 and R1 000 000, the requisition must be signed off by the Procurement and Materials Manager as evidence that he/she reviewed the requisition to ensure that the requisition complies with the procurement policy. This is an essential part of the procurement process, but it is potential bottleneck operation.

From the survey, a significant 33% of purchase requisitions for research equipment and services took more than 2 days. From the raw data of the survey, the nature of these items or services bought was complex and high value (as per the delegation authority), thus elucidating the inefficiencies while waiting specification confirmation. This aspect relates to 7.6 % which is the satisfaction with requisition processing time.

The recommendation for improvement of the requisition conversion process is to implement key performance indicator tracking. The main indicator to be tracked is the time between capturing of the approved requisition system to when there it is converted to a purchase order. This will assist in flagging the requisitions that have not been converted and creating alerts to the initiators so that they can furnish the procurement team with the outstanding documents such as quotations or specific requirements for the type of requisition mentioned in Figure 4. It is important to note that this should be tracked by the procurement team as well and must form a fundamental key performance area of the department.

The conversion is a critical impactor in the lead time of the equipment delivery. If there are delays in during the conversion of requisition to purchase order, it will be a bottleneck in the system.

The second component of the recommendation is the implementation of the DMAIC methodology to for continuous improvement to study the time taken to convert the requisition into a purchase order. This section will use methodology as in 7.8 and Lean Management + vertical integration since it involves both lean management and industry 4.0 initiatives implemented on internal organisational systems.

7.11. Time Taken to Release Purchase Order to Supplier

As indicated in Figure 30, a significant 74% of the respondents had their purchase orders released to suppliers for fulfilment between 0 to 7 days. For the rest of the respondents, this was more than 1 week. This indicates some inefficiencies. From the raw data of the survey, the nature of these items or services bought was complex and high value, thus explaining the delays while waiting specification confirmations.

It is important to employ a methodological approach in identifying the exact problems and inefficiencies and logically generate solutions to address the inequalities. Additionally, to the survey that has been done, the DMAIC methodology will be deployed to identify the inefficiencies, identify solutions, implement changes and continuously improve the time taken to release the purchase order to the supplier.

The solutions and recommendations that will come out the DMAIC process may related to Industry 4.0 initiatives or traditional lean management tools. The problem-solving component of this recommendation is the implementation of the DMAIC methodology to for continuous improvement of the time taken to release the purchase order to the supplier for fulfilment. This section will use methodology as in 7.8 and Lean Management + Horizontal integration since it involves both lean management and industry 4.0 initiatives implemented on internally and external suppliers' organisational systems.

The workflow management process and solution envisaged in 7.5 will cover this area with the strong emphasis on time limits definitions that will trigger a push notification through email, Microsoft Teams, and other means such as the WhatsApp or Short Messaging Service (SMS) once the purchase order has stayed on the system without being released to the supplier. Once this notification is sent to the initiator, procurement staff, approver and budget officer, it will allow editing and upload of the outstanding documents that can be uploaded digitally via the mediums of communication specified above. This then links to the ERP system and purchase order will be auto released to the supplier via a live link that can allow uploading of invoices, queries or completion of order notification. This link feeds to the ERP system and updates any changes on status of order. The action is prompted onto the workflow management system, where for example, the creditors can get the digital push notification to alert them of service or product completion so that payment can be processed.

7.12. Product/Service Processing Time by Supplier

The results indicated that 53% of the respondents had their items manufactured between in less than 2 weeks. For 19 percent of the respondents, the supplier produced their items between three and six weeks. For the rest of the respondents, this was more than 11 weeks. From the raw data of the survey, there were delays in supplier payment and due to the nature and high value of items, some were delayed in the tender committee process.

The nature of the research equipment affects the time taken for the suppliers to manufacture the equipment. The internal factors that the university is in charge of such as the processing of requisitions and purchase orders, contract management, and approval processes are going to be addressed at an organisational level. However, inefficiencies that the suppliers have, may be addressed on using Big Data for smart contracts.

The usage of Big Data in procurement will be used to analyse contracts, expenses, Key Performance Indicators of the suppliers. The Big Data application will collect and digitise data from previous invoice, contracts, delivery times, lead times, supplier locations and its climate. The Big Data focused solution will maximise current data and can complement with big insights that can be shared with the suppliers during contract negotiations to improve compliance to service level agreements.

One of the benefits of using Big Data smart contracts are that the supplier risks are minimised. If the insights reveal that the current contracted supplier is at risk of not supplying the research equipment due to an abnormal event, dynamic emergency plans can be activated so that an alternative supplier can be utilised. This can also provide a solution on fair and dynamic prices that reflect the current economic events by using Big Data analytics to implement fact-based pricing. This can assist the university to avert unfair pricing.

From both studies in this simulation section, the models can be developed to imitate various scenarios. The results from the simulation studies can provide data that may assist inform the procurement team to develop risk management strategies for extreme events that can disrupt the supply chain system. Furthermore, contracts renewal scenarios can be simulated to further inform decision makers.

To assist the suppliers that have high value contracts with the university, a supplier continuous improvement program can be implemented to assist with eliminating manufacturing inefficiencies at the supplier site. Continuous Improvement Methodologies such as Single minute exchange of Dies (SMED) can be implemented to reduce the setup times for the suppliers' production lines. This allows a dual benefit system where the university can get its research equipment quicker and the supplier benefits by improving overall production efficiency and productivity.

7.13. Supplier Payment Delays

While 76% of the respondents expressed that their equipment suppliers did not experience any payment delays, 24% expressed that their supplier were not paid on time. The general payment term is 30 days after receipt of goods or services. With the provision that the goods or services supplied are to the complete satisfaction of the university and all the correct documentation is furnished to the creditors section timeously.

The common issues on the payment of suppliers stem around final price discrepancies, the use of cheque payments, inflexible Cash on Delivery (COD) authorization policy. For the COD payment method there must be a signed undertaking to be completed by the approver accepting full responsibility for the receipt of the items and the forwarding of the signed invoice to Finance once delivery takes place. This is an additional burden and bureaucratic process delaying the procurement of the research equipment.

The use of Value Stream Mapping (VSM) can be used to eliminate the inefficiencies in the supplier payments. The use of VSM will assist in identifying nonvalue adding activities. The causes of bottlenecks can be identified using Ishikawa diagram (cause and effect diagram) and devising an action plan. For continuous improvement, various strategies such as Plan-Do-Check-Act (PDCA), can be used to standardize and continuously improve the payment process.

The suppliers that preferred cheque payments method may experience delays as this method takes more time to clear into the business bank account. Effective from 1 January 2021, this payment method is no longer used in South Africa [190]. Among others, the Reserve Bank of South Africa cites many challenges round this payment method including

- a prolonged processing periods
- risk of fraud on the issuing of cheques
- costly payment mechanism
- limited reception of cheques by businesses
- declining usage and ageing interbank cheque processing infrastructure

Due to the reasons stated above for the discontinuation of cheques, the recommendation will not include any suggestions on this payment method.

7.14. Order Delivery Time by Supplier

The analyses show that 80% of the respondents had their items delivered in less than 2 weeks which seems reasonable for research equipment. It took between three and six weeks for suppliers to deliver items for 15% of the respondents. For 5% of the respondents, this was more than 11 weeks. This is considerably along time to transport equipment. Mostly this will be items ordered from international suppliers. From the raw data of the survey, there were delays in delivery time and due to COVID-19 pandemic delays in the harbours and freight vessels.

Internally, the university may not have full control of this situation where the equipment delivery took is 11 weeks. However, there are strategies that can be implemented which commence by understanding the issues and nature of equipment that is affected. Through DMAIC and value stream mapping exercise, the gaps and inefficiencies in the transportation will be identified and defined. For the measure, analyse, improve, and control phase will be implemented using methodology as explained in Figure 51, Figure 52 and Figure 53.

The easily achievable solutions include usage of faster modes of transportation such as air freight instead of sea freight. Additionally, the university is located close to the

Dube Trade Port which specialises in air cargo and located within 35 kilometres. This can be utilized where the research equipment is needed immediately thereby cutting the waiting time. The air freight only mode may be more expensive.

The university may consider using the multimodal transportation by combining the sea and air transportation modes. The main features of multimodal transportation include the following

- A reduction of number of days taken to transport equipment paralleled to the sea-only transportation [191]
- Less expensive carriage prices compared to air-only mode [191].

7.15. Asset Registration Time

For the significant 40.8 % of the respondents, their research equipment was registered on the asset registry after 7days or 1 week. This is considerably a long time as it adds on the idle time that the equipment is stored without being used. That time can be utilised on the installation and actual research. One of the difficulties was the equipment purchased during the COVID19 pandemic, where the items took longer to be registered on the asset register. This was due to remote working schedules for the researchers, students and staff.

Procedurally, the items have to be stored at the warehouse when delivered, so that they can be tagged before being moved to the departmental laboratory or office of the requisition initiator. However, this is currently not happening as there is limited warehouse storage in the stores department. So, it is briefly received outside the warehouse and then moved to the department of the initiator before the end of the day whether tagged or not. When the assets department physical came to offices for tagging, the equipment custodians were either working at home or not available to open offices.

A potential strategy that can be implement is the utilisation of smart tags with RFID by the asset management department for tracking and can be integrated with app-based tracking. These RFID tags will be stuck onto the research equipment during the temporary holding just after delivery. The items will be moved to departments after these smart RFID have been tagged to items. The RFID tags and Bluetooth tags can be then labelled “registered’ or “yet to be registered” on the web-based application linked to the asset registration software. The RFID tags provides a tracker that can be used to later register the research equipment without delaying the researcher on the use of equipment. The integration of the tags and smartphone applications through android applications for the search and track function will be employed in this Industry 4.0 solution.

7.16. Installation Time

As explained in Figure 37, 55% of the respondents had their research equipment installed for use between 0 and 1 days. Notably, on overall, 78% of the respondents had their items installed for use in 1 week. This depends on the type of research equipment and complexity of equipment. It took between one and two weeks for items installed for 8% of the respondents. For the rest of 14% the respondents, this was more than 2 weeks. This may be due to that the user manuals were not clear enough or that the staff needed to be trained by the supplier for the assembly process for components.

The user manual is critical for correct installation of the research equipment. When the instructions are not followed accurately, the equipment may not function thus delaying the research process while it gets reassembled again. One other challenge is that the instructions may not be clear enough. Li et al. [192], methodically investigated the variances between Chinese and Western user manuals by analysing contents of user manuals written in Chinese and Western for domestic appliances. Their results show that Western manuals were more strictly limited to user support than that of Chinese manuals and had fewer visual illustrations. This points out that the supplier selection criteria need to take care into cognisance of the after sales support offered by the selected supplier.

The user of Augmented Reality and Virtual Reality may be implemented as to assist the technicians during the research equipment assembly and installation. Whenever they get stuck, they can refer to the AR application on the ERP system linked to the purchase order or item number. This can link the user to the supplier platform where they can use the AR or VR to follow the correct steps of equipment assembly on the virtual showroom. The main difference between Augmented Reality from Virtual Reality is that, with AR, virtual objects are combined in 3D into a real environment and are projected in real-time display while VR completely replaces reality [193].

7.17. ERP System Usability

On a 1-100% scale, the users rated the current ERP System usability at 70.5 %. At the time, the research is being conducted, there has been a management decision by the university to phase out the current ERP System and implement a much more innovative, integrated and versatile yet robust. The recommendations on this aspect will be limited to the implementation phases of the system. Table 22 below shows the activities in each phase of implementation from the definition to the implementation phase.

Table 22: The recommended overall phases of the new ERP system

	Phases of Implementation for the new ERP System				
	Definition	**Requirements Definition**	**Solution Design**	**Transition**	**Full utilization**
Activities	Run roadshows and workshops with departments with project team to explain new ERP concepts and present main functions	Run a gap analys is between business requirement and ERP functions	Run an architype to validate the envisaged ERP solution design	Transfer data	Train final users
			Develop an interface between for integration ERP list of materials & student data	Prepare the university environment for the new ERP System	Implementation
	Backup and Clean-up current data with the Current ITSS system		Run integration test involving ERP, interfaces, custom extensions and reports		System Monitoring

The activities and phases above only show the overall definition of the implantation plan and are not exhaustive as there are many revisions envisaged during the process. The IT department may also utilize the external providers and other support personnel. This research study does not form part of the new ERP implementation.

7.18. Location of Recommendations within the Constructs

It is important that the recommendations in this chapter can be categorised and be located into the two initiatives namely Lean and Industry 4.0. The table below summarises the recommendations against the problems identified by the survey and the classification of each recommendation.

Table 23: Location of recommendations within the constructs

No	Recommendation	Problem being addressed	Classification
1	Visibility Flowchart with procurement Steps, Process Diagram, responsible persons and their contact Information	The procurement team and their responsibilities are not known by 37.7% of the respondent	Lean Management
2	The use of robotics applications such as a chatbot	46.9% of the respondents perceived the procurement team to be sometimes and rarely responsive	Industry 4.0 Robotics (Applications)
3	Using Augmented Reality and Virtual Reality Applications for visualisation of the research equipment and correct specifications of items can be clarified before manufacturing researchers at the institution	The combined 33.8% of the respondents perceived the procurement team to be sometimes and rarely accurate	Industry 4.0 (Augmented Reality, Virtual Reality)
4	Digitized workflow management for the delegation authority for requisition approval	a significant 25% were dissatisfied with the time taken to approve the requisition by management	Lean Management + Industry 4.0
5	Implementation of key performance indicator tracking. (Time between capturing of the approved requisition system to when there it is converted to a purchase order)	25% dissatisfaction rate with the time taken to convert the purchase requisition to purchase order.	Lean Management
6	Robotics Process Automation for automatically filling the	Delayed procurement from manual requisitions being lost	Industry 4.0

No	Recommendation	Problem being addressed	Classification
	fields of the digital requisition form and online bidding		(Robotic Process Automation)
7	DMAIC for to analyse and eliminate all inefficiencies in the process requisition preparation time.	Significant 23.8 % took more than eight hours to prepare requisition.	Lean Management
8	DMAIC methodology to improve time taken to approve the requisitions + Digitized workflow management for the delegation authority for requisition approval	To reduce the requisition approval time	Lean Management
9	Implementation of key performance indicator tracking + DMAIC methodology to eliminate inefficiencies of the requisition conversion process	To reduce the time taken to convert the requisition into purchase order.	Lean Management
10	DMAIC process to identify the inefficiencies, identify solutions, implement changes and continuously improve the time taken to release the purchase order to the supplier + Digitized workflow management for the notification of unreleased purchase orders	To reduce the time taken to release the purchase order to the supplier	Lean Management
11	Usage of Big Data applications to collect and digitise data from previous invoice, contracts, delivery times, lead times, supplier locations and its climate. the simulation studies can provide data that may assist inform the procurement team to develop risk management strategies for extreme events that can disrupt the supply chain system	To assist with improving time taken to manufacture research equipment	Industry 4.0 (Simulation) (Big Data)
12	The use of Value Stream Mapping (VSM) can be used to eliminate the inefficiencies in the supplier payments.	Inefficiencies in the supplier payment process	Lean Management (VSM)

No	Recommendation	Problem being addressed	Classification
13	DMAIC and value stream mapping exercise, the gaps and inefficiencies in the transportation will be identified and defined. Intermodal transportation can be utilised as well	Inefficiencies in time taken to deliver the equipment	Lean Management (DMAIC) VSM
14	the utilisation of smart tags with RFID by the asset management department for tracking and can be integrated with app-based tracking	Inefficiencies in the asset registration and management of research equipment	Industry4.0 (RFID)
15	The use of Augmented Reality and Virtual Reality may be implemented as to assist the technicians during the research equipment assembly and installation	Inefficiencies in the research equipment assembly and installation process	Industry 4.0 (RFID)

The KPI’s that can be linked to the recommendations are presented in Appendix E. The are some of the basic key performance indicators that will assist in tracking the improvements that come from the implementation of the reformations. They include the frequency of tracking and people responsible. Importantly, the university is currently employing a new ERP system, and this will require the revision.

8. CHAPTER EIGHT: CONCLUSION

8.1. Introduction

This chapter summarises the study, provides conclusions and future work.

8.2. Summary of Research Study

The aim of the research study was to investigate implementation techniques that an organisation can employ to advance supply chain process efficiency by integrating lean management and Industry 4.0 initiatives in the procurement process for research equipment at an institution of higher learning.

In conducting the research on the constructs and models of integration, the study was steered by the research questions below (as presented in section 1.3.3):

- What are the current practices and efficiencies in the procurement process for research equipment at DUT?
- What are the integration models that can be used to implement Industry 4.0 and lean management for an integrated continuous improvement approach?
- How can lean management and industry 4.0 initiatives be implemented in an integrated manner to advance supply chain
- What are the solutions from lean management and Industry 4.0 that can be recommended to improve supply chain efficiency for the procurement process?

The above the sub-questions assisted in responding to the consequent main research question:

"How can an institution of higher learning implement Industry 4.0 and lean management in an integrated approach to advance supply chain process efficiency for the research equipment procurement?"

In addressing the research questions, the organisational structure, procurement process was mapped and the delegation authority for approval presented to lay the operational background for the study.

Furthermore, a survey was sent to respondents to ascertain the efficiency of the current procurement process for research equipment at the university. In order to develop recommendations based on the lean management and industry 4.0 initiatives, the integration models were investigated to assist in developing a framework of an integrated implementation of recommendations to advance productivity and business objectives.

Specific constructs analysed in this study include ERP systems, lean six sigma, DMAIC, lean office tools, Industry 4.0 Digitalization enablers such as Big Data, Augmented Realty, Internet of Things, 3D Printing, Robotic Process Applications, and RFID. Furthermore, a targeted literature analysis of peer reviewed journal articles was done, where the constructs of lean and Industry 4.0 have been implemented successfully were analysed and potential applications were established.

The study then formulates recommendations of improving the process efficiency and productivity for the research equipment procurement process. The recommendations include suggestions on how the lean management and industry 4.0 related can be integrated together during the implementation of recommendations. The recommendations address the inefficiencies that were identified using the survey.

8.3. Limitations

The study considered lean management and Industry 4.0 applications as the main drivers of advancing productivity in supply chain processes. It was limited to the context of higher education sector and a university procurement process. The integration models of lean management and Industry 4.0 applications were limited to the two models by [140] and [141] comprising of three-theoretical models (vertical integration with lean management, horizontal integration plus lean management as well as end-to-end engineering integration and lean management).

The survey was limited to three groups of people namely, the administration staff responsible for purchasing research equipment, 2nd year fulltime doctoral students and postdoctoral fellows. This application of the Public Finance Management Act as the university forms part of the unlisted public entities as per the PFMA Act (Public Finance Management Act, No. 1 of 1999, 2018).

8.4. Future work

The institution is in the process of implementing the new ERP system and this will have major implications for the institutional processes including the research equipment procurement process. After the implementation of the recommendations, it will be also crucial to measure the effectiveness and improvement by tracking the key performance indicators. These will indicative whether there are any significant benefits in using the integration models of lean and industry 4.0 applications and how can they be amplified further for higher productivity and enhancement of business objectives.

8.5. Contributions of the study

The study tests the practicality of integration models for lean management and industry 4.0 by Wang [136] and Sony [137]. The constructs of these integration models form a firm foundation for formulation of industry 4.0 orientated solutions with lean management. The study also provides foundations for validating the constructs of integration models and an opportunity to make dynamic additions or deletions for further improvement.

The study makes a contribution by proving a blueprint that can be followed by an organisation to investigate supply process efficiency, identify areas of improvement, propose solutions, provide an implementation plan and provide tracking mechanism.

The novelty of this research is that it proposes a practical approach of integrating industry 4.0 and lean management, not only from the point of theoretical framework but real-world application. It also identifies synergies in implementing both Industry 4.0 and lean management as to avoid contrasting actions.

In summary, this study investigates supply chain efficiencies, tests the implementation of integration models for Industry 4.0 and lean management, thus showing how it can be applied in practice to make recommendations aimed at improving the supply chain efficiency.

8.6. Concluding remarks

The aim of the research study was to investigate implementation techniques that an organisation can employ to advance supply chain process efficiency by integrating lean management and Industry 4.0 initiatives in the procurement process for research equipment. This was achieved by:

- Investigating current practices and efficiencies in the procurement process for research equipment at an institution of higher learning.
- Reviewing models for integration of both management approaches in order to suggest a seamless integrative approach that can be implemented by organisations.
- Researching case studies where lean management and industry 4.0 have been implemented, with a view to develop grounded model solutions to address inefficiencies in the procurement process being studied.
- Proposing solutions grounded from lean management and Industry 4.0 to improve supply chain efficiency for the research procurement process.

The results from the survey showed that there are inefficiencies in the procurement process followed for the purchasing of research equipment. The literature survey for previous applications of lean and industry 4.0 applications provided a fundamental foundation for the development of recommendations to improve the procurement process for advancement of business objectives and improvement of productivity.

The classification of these recommendations into the two categories of lean & industry 4.0 business improvement techniques was essential so that they can be identified within constructs of integration models of Wang et al. [140] and Sony [141]. The successful implementation of these recommendations can form a basis and a blueprint that organisations can use to replicate implementation of both industry 4.0 and lean applications and identify synergies between the two techniques and avoid contrasting actions. The proposed key performance indicators in Appendix E are key in tracking the efficiency of the procurement process.

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APPENDIX A: TURNITIN REPORT FOR ORIGINALITY

Thesis 2022

ORIGINALITY REPORT

9%	8%	8%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.tandfonline.com Internet Source	2%
2	hdl.handle.net Internet Source	1%
3	uir.unisa.ac.za Internet Source	<1%
4	ujcontent.uj.ac.za Internet Source	<1%
5	ftp.idu.ac.id Internet Source	<1%
6	www.researchgate.net Internet Source	<1%
7	Aysegul Yilmaz, Manoj Dora, Behzad Hezarkhani, Maneesh Kumar. "Lean and industry 4.0: Mapping determinants and barriers from a social, environmental, and operational perspective", Technological Forecasting and Social Change, 2021 Publication	<1%

APPENDIX B: ETHICS APPROVAL

UNISA university of south africa

UNISA SOE ETHICS REVIEW COMMITTEE

Date: 10/03/2020

Dear Mr. Bongumenzi Talent

Decision: Ethics Approval from 10/03/2020 to 10/03/2023

ERC Reference # : 2020/CSET/SOE/002

Name : Mr. Bongumenzi Talent

Student #: 49953702

Staff #: N/A

Researcher(s): Name: Mr Bongumenzi Talent
E-mail address: btmagaye@gmail.com
Telephone #: 0738917453/ 0614459727

Supervisor (s): Name: Prof Kemlall Ramdass
E-mail address: ramdakr@unisa.ac.za
Telephone #: 0824173545/011 4712171

RECEIVED
2020 -03- 10
OFFICE OF THE EXECUTIVE DEAN
College of Science, Engineering and Technology

Co-Researcher(s): N/A

Working title of research:

Integration of Industry 4.0 with lean management in supply chain environments to advance productivity and business objectives

Qualification: PhD

Thank you for the application for research ethics clearance by the Unisa SOE Ethics Review Committee for the above mentioned research. Ethics approval is granted for 5 years.

RECEIVED
OFFICE OF THE DIRECTOR
10 -03- 2020
School Of Engineering
College of Science, Engineering and Technology

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
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*The **negligible risk application** was **reviewed** by the SOE Ethics Review Committee on 10/03/2020 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment. The decision was approved on 10/03/2020.*

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the SOE Committee.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No field work activities may continue after the expiry date 10/03/2025. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.
8. Field work activities may only commence from the date on this ethics certificate.
9. [Permission to conduct research involving UNISA employees, students and data should be obtained from the Research Permissions Subcommittee (RPSC) prior to commencing field work.] AND/OR
10. [Permission to conduct this research should be obtained from the [company, CE organisation, DoE, etc name] prior to commencing field work.]

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Add any other conditions if relevant.

Note:

*The reference number **2020/CSET/SOE/002** should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

Signature..

Prof E Onyari-Benecha

Chair of SOE ERC

E-mail: onyarek@unisa.ac.za

Tel: (011) 471-3379

Signature..

Prof BB Mamba

Executive Dean : CSET

E-mail: mambabb@unisa.ac.za

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10/03/2020

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APPENDIX C: CONSENT LETTER

INVITATION TO PARTICIPATE IN STUDY: An assessment of the efficiency of procurement process for research equipment.

Dear Colleague

I trust that you are well.

Please be so kind to take five minutes of your time and participate in my PhD study.

I am registered for a Doctor of Industrial Engineering degree at the University of South Africa (UNISA), I am interested in inviting you to take part in this study titled: **An assessment of the efficiency of procurement process for research equipment**. The main topic for the thesis is: ***Integration of Industry 4.0 with lean management in supply chain environments to advance productivity and business objectives.***

This study aims to carry out an in-depth assessment of the problems and delays experienced by the researchers when buying research equipment/services and how this process can be improved. You have been selected for this research because you are a researcher and have possibly procured equipment or services during your study e.g., statistician services, software, laptop for research, transcriber etc.

Please complete the questionnaire by selecting the option that reflects your response to the statement/question. CLICK HERE TO PARTICIPATE IN THIS STUDY.

Kindly disregard this email if you have already participated in the study.

You contribution towards my study is most appreciated.

Thank you

Kind regards
Bongumenzi Mncwango

Doctoral Researcher
Department of Industrial Engineering
University of South Africa (UNISA)

APPENDIX D: SURVEY

INVITATION TO PARTICIPATE IN STUDY: A assessment of the efficiency of procurement process.

My name is Bongumenzi Mncwango and registered for a PhD Industrial Engineering degree at the University of South Africa (UNISA). I am inviting you to take part in this study titled: An assessment of the efficiency of procurement process for research equipment. The main topic for the thesis is: Integration of Industry 4.0 with lean management in supply chain environments to advance productivity and business objectives.

This study aims to carry out an in-depth assessment of the problems and delays experienced by the researchers when buying research equipment and how this process can be improved. You have been selected for this research as you are using the research equipment procured by the university.

"Taking part in the study is voluntary, and you are allowed to withdraw your involvement at any stage of the project without any negative repercussions and/or fear of being prejudiced against. There will be no monetary benefits for your participation in the project. Confidentiality and anonymity will be ensured and where appropriate coded/disguised names of respondents/institutions will be used. Please complete the questionnaire by selecting the option that reflects your response to the statement/question."

*Required

1. I hereby confirm that I have been informed by the researcher and that my participation in this study is voluntary *

Mark only one oval.

- ◯ Yes
- ◯ No

2. Please enter the name of equipment or service that you purchased using the university procedure *

____

3. Affiliation To University *

Mark only one oval.

- ◯ Staff
- ◯ Student
- ◯ Researcher

4. Gender *

Mark only one oval.

- ( ) Female
- ( ) Male
- ( ) Other: ____________

5. Department

____

6. Race *

Mark only one oval.

- ( ) African
- ( ) White
- ( ) Indian
- ( ) Asian
- ( ) Colored

7. Faculty *

Mark only one oval.

- ◯ Health Sciences
- ◯ Arts & Design
- ◯ Management Sciences
- ◯ Accounting & Informatics
- ◯ Applied Sciences
- ◯ Engineering & Built Environment
- ◯ Other: ____________________

8. Are you familiar with the structure of the procurement / purchasing team, who is responsible for what, and how to contact them? *

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Maybe

9. How would you rate the procurement team on Responsiveness? *

Mark only one oval.

- ◯ Rarely
- ◯ Sometimes
- ◯ Mostly
- ◯ Always

10. How would you rate the procurement team on Accuracy? *

Mark only one oval.

- ◯ Rarely
- ◯ Sometimes
- ◯ Mostly
- ◯ Always

11. Are you satisfied with the speed that your requisition is approved by the HOD/Line manager? *

Mark only one oval.

- Yes
- No

12. Please specify any delays/inefficiencies experienced

13. Are you happy with the speed at which your order was processed by procurement once your requisition has been approved by HOD/Line Manager? *

Mark only one oval.

- Yes
- No

14. Please specify the areas that are generally lacking on the processing speed of your equipment order by procurement

15. What Enterprise Resource System (ERP) system did you use for procurement process of your equipment? *

Mark only one oval.

- ◯ Manual Process
- ◯ ITSS
- ◯ Hybrid(Manual + Other Automated System)
- ◯ Other: ____________________

16. Is the ERP System efficient for your procurement needs (specifically for research equipment)? *

Mark only one oval.

- ◯ Yes
- ◯ No

17. Please specify any problems experienced while using the system

18. How user friendly is your procurement module for your ERP System? (Choose one, 5 being the most user friendly and 1 being least user friendly) *

Mark only one oval.

1	2	3	4	5
○	○	○	○	○

19. How much time do you spend preparing your requisition? *

Mark only one oval.

- Less than 1 hour
- Between 1 and 3 hours
- 3 - 8 hours
- 8 -24 hours
- 1-2 days
- More than 2 days

20. How much time was taken for your acquisition to be approved by HOD/Line Manager? *

Mark only one oval.

- Less than 1 hour
- Between 1 and 3 hours
- 3 - 8 hours
- 8 -24 hours
- 1-2 days
- More than 2 days

21. How much time was taken to approve your order on the ERP System by procurement department? *

Mark only one oval.

- ( ) Between 0 and 3 hours
- ( ) 3 - 8 hours
- ( ) 8 -24 hours
- ( ) 1-2 days
- ( ) 2-7 days
- ( ) More than 7 days (please specify duration)

22. How much time did it take for the order to be made available to the supplier after approval by procurement? *

Mark only one oval.

- ( ) Between 0 and 1 day
- ( ) 1-2 days
- ( ) 2-7 days
- ( ) 1-2 weeks
- ( ) 2-4 weeks
- ( ) More than 4 weeks

23. How much time did it take for the supplier to produce or supply your equipment/service after receiving the order from procurement team? *

Mark only one oval.

- Between 0 and 1 day
- 1-2 days
- 1-2 Weeks
- 3-6 weeks
- 7-10 weeks
- 11-20 weeks
- More than 20 weeks

24. Were there any delays in paying the supplier? *

Mark only one oval.

- Yes
- No

25. If yes, please specify the reason

26. How much time was taken for your equipment to be delivered to your after the supplier finished producing your part? *

Mark only one oval.

- Between 0 and 1 day
- 1-2 days
- 1-2 Weeks
- 3-6 weeks
- 7-10 weeks
- 11-20 weeks
- More than 20 weeks

27. After the equipment was delivered, how long did the asset management division take to register it on the asset register? *

Mark only one oval.

- ( ) Between 0 and 1 day
- ( ) 2-7 days
- ( ) 1-2 weeks
- ( ) 3-5 weeks
- ( ) More than 5 weeks

28. How long was the installation of the equipment for use? *

Mark only one oval.

- ( ) Between 0 and 1 day
- ( ) 2-7 days
- ( ) 1-2 weeks
- ( ) 3-5 weeks
- ( ) More than 5 weeks

APPENDIX E: KEY PEFORMANCE INDICATORS FOR TRACKING OF EFFICIENCY

Item	Summarised Problem Area	Summarised Recommendation	Key Performance Indicator	Frequency	Tracking Level	Person Responsible
Acquaintance with the procurement team	47.7% percent of the respondents knew the procurement team and structure while 14.6% were not sure if they knew the procurement team and structure. The remaining 37.7% did not know the procurement team and who to contact for purchase order tracking and other queries.	Improved organogram to be sent to each researcher and postgraduate student upon entry and quarterly through email and push notification	Number of reminders sent to researchers	Quarterly	Tactical	Procurement Department Head
Responsiveness of the procurement team	46.9 % of the respondents perceived the procurement team to be sometimes and rarely responsive, thus not very satisfied of their responsiveness.	Integration of the chatbot to the ERP system for the purchase requisition initiators for properly tracking and effective communication with the procurement team.	Number of queries solved via the chatbot	Weekly	Operational	Procurement Officers
Order Accuracy	A combined 33.8% of the respondents perceived the procurement team to be sometimes and rarely accurate, there needs to be	Implementation of AR and VR to visualise the product and correct specifications of items can be clarified before the product is manufactured or delivered	Number of requisitions and orders with incorrect specifications	Weekly	Operational	Procurement Officers

Item	Summarised Problem Area	Summarised Recommendation	Key Performance Indicator	Frequency	Tracking Level	Person Responsible
	solutions provided to avert this.	to the researchers at the institution.	% Accuracy for requisitions and orders	Weekly	Operational	Procurement Officers
Satisfaction with requisition approval time	A significant 25% were dissatisfied with the time taken to approve the requisition by management	Streamlining of the delegation of authority needs to be further conducted so that there is a clearer process of approvals especially when the managers are on leave and not available to physical approve the requisitions.	Number of unsigned requisitions on the ERP System by Management	Every 2 days	Operational	HOD in which the requisition is raised as per delegation system
Satisfaction with order processing time	The survey indicated that 75% of the respondents were satisfied with order processing time while 25% were dissatisfied with the tome taken to convert the purchase requisition to purchase order.	This will assist in flagging the requisitions that have not been converted and creating alerts to the initiators so that they can furnish the procurement team with the outstanding documents such as quotations or specific requirements for the type of requisition	The time between capturing of the approved requisition system to when there it is converted to a purchase order.	Biweekly	Tactical	Procurement Team Head of Sections
		Procurement will then send this to each requisition initiator copied manager to sort out the outstanding requirements	% incomplete requisitions	Weekly	Operational	Administrative Staff for respective department

Item	Summarised Problem Area	Summarised Recommendation	Key Performance Indicator	Frequency	Tracking Level	Person Responsible
ERP System – Type of Order Entry	The manual process was used by 27% of the respondents. The ordering system is not fully digitised and some orders above R10 000 have to be completed via the hybrid or manual paper	Digitalization of procurement to the ITSS enabler for the time being, while the university is in the process of implementing the new ERP system which will enable the expansion of functionalities of the procurement module.	% of orders completed via digital ITSS module	Monthly	Tactical	Procurement Team Head of Sections
			% of manual orders completed	Monthly	Tactical	Procurement Team Head of Sections
Requisition preparation time	23.8 % took more than eight hours to prepare requisition. This is quite a long time to obtain the required number of quotations from suppliers and preparation of summary of quotations form.	To provide a structured solution for this challenge, a lean management initiative of DMAIC can be used systematically and structurally, to analyse and eliminate all inefficiencies in the process.	possible KPI's to be tracked: time take to complete the requisitions	Monthly	Tactical	DMAIC Project Team
			number of requisitions with incomplete quotations	Fortnightly	Operational	Procurement Performance Analyst
			number of requisitions with incomplete documentation (excluding quotations)	Fortnightly	Operational	Procurement Performance Analyst

Item	Summarised Problem Area	Summarised Recommendation	Key Performance Indicator	Frequency	Tracking Level	Person Responsible
Requisition approval time	A significant 29.2% of the respondents had their requisitions approved after 2 days, which is a long time for a signature	The workflow management process and solution envisaged in 7.4 will cover this area with the strong emphasis on time limits definitions that will trigger a push notification through email, Microsoft Teams and other means such as the WhatsApp or Short Messaging Service (SMS).	Number of workflows not approved within the day	Daily	Operational	Procurement Performance Analyst
Order Entry time on the system after approval	a significant 33% of purchase requisitions for research equipment and services took more than 2 days which is a long time for an entry on the system	Efficient Tracking of KPI's related to the order entry time	Time between capturing of the approved requisition system to when there it is converted to a purchase order.	Weekly	Operational	Procurement Officers
Time taken to release purchase order to supplier	26% of the respondents had their purchase orders released to suppliers for fulfilment after 7 days	The workflow management process and solution envisaged in 7.4 will cover this area with the strong emphasis on time limits definitions that will trigger a push notification through email, Microsoft Teams and other means such as the	Time taken to release purchase order to supplier after entry	Weekly	Operational and Tactical	Budget Officers, Procurement Officers, Finance Managers for respective heads

Item	Summarised Problem Area	Summarised Recommendation	Key Performance Indicator	Frequency	Tracking Level	Person Responsible
		WhatsApp or Short Messaging Service (SMS).				
Asset registration time	For the significant 40.8 % of the respondents, their research equipment was registered on the asset registry after 7days or 1 week. This is considerably a long time as it adds on the idle time that the equipment is stored without being used.	Utilisation of smart tags with RFID by the asset management department for tracking as well as integration of app-based tracking. These RFID tags will be stuck onto the research equipment during the temporary holding just after delivery. The items will be moved to departments after these smart RFID have been tagged to items. The RFID tags and Bluetooth tags can be then labelled “registered’ or “yet to be registered” on the web-based application linked to the asset registration software.	% Tagged Items on the items	Daily	Operational	Maintenance Team
			% Untagged Items on the items	Daily	Operational	Maintenance Team