BIRMINGHAM CITY University

A Maturity Model to Improve Inventory Management Systems in SMEs

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First and foremost, Thanks and gratitude to Allah Almighty for the patience, strength and motivation for this achievement.

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Abbreviations

IMS Inventory Management System

WMS Warehouse Management System

STS Socio-Technical System

AIT Automated Identification Technology

OPPT Organisational, People, Process Technology

IMCCT Inventory Management Context Capture Tool

IMSMM Inventory Management System Maturity Model

Abstract

Accurate inventory data is critical for effective inventory management to meet customer demands. Although inventory management systems (IMS) integrate processes, inaccurate inventory data remains a significant problem in small to medium enterprises (SMEs).

Existing research to improve inventory data accuracy focuses on discrete solutions implemented in isolation, such as automated inventory tracking and inventory storage policies, with limited success. Recent research highlights that challenges of inventory data inaccuracy still exist and are not one-directional but are interrelated, identifying the need for a holistic socio-technical systems approach to address inventory data challenges collectively to improve inventory management systems. The thesis addresses this gap by proposing a maturity model and a supporting practical application framework to enable SMEs to adopt a socio-technical systems approach to assess and address the causes of inaccurate inventory data, thus improving the operation of inventory management systems.

A thematic literature review adopted a socio-technical systems lens in identifying inventory data quality measures and categorising inventory management systems challenges and critical success factors into four areas: Organisational, People, Process, and Technology (OPPT). The literature findings were validated through primary data collection with inventory managers of 5 e-commerce retail SMEs in West Midlands, UK. Rich pictures were developed to analyse the interview data and the application of soft systems methodology was used to identify improvements to inventory management systems in SMEs. This led to the development of a practical application framework consisting of 3 stages: (i) Context capture to identify the nature of inventory management systems in an SME (IMCCT), (ii) Inventory Management System Maturity Model (IMSMM) to assess the current state of inventory management in an SME and (iii) Recommended actions to improve inventory management systems. The maturity model adopts a socio-technical approach by assessing maturity across all four socio-technical areas (OPPT) and identifying improvements to be implemented jointly across these areas. The maturity model was validated through application in an SME, leading to improvements in the accuracy of inventory data in the SME, improving maturity from

31% to 66%, reducing the inaccuracy from 10.21% to 0.53% and saving just over £22,000 within six months.

This thesis demonstrates the importance of adopting a socio-technical systems approach to improve inventory management systems and proposes a maturity model to address the research gap of how to adopt a holistic socio-technical systems approach to improve data accuracy in inventory management systems in SMEs. A second theoretical contribution is a set of data quality measures to assess inventory data. It is proposed that the approach can improve data quality in other domains. This thesis's methodological contribution is its novel application of soft systems methodology in using rich pictures to analyse interview data. This was continued into applying the stages of SSM producing a CATWOE analysis, root definition and a conceptual model, which was used to develop the framework. The framework, including the inventory management system maturity model (IMSMM), is a practical contribution for e-commerce SMEs that has achieved a measurable impact in improving the accuracy of inventory data in inventory management systems.

1 Introduction

The chapter introduces the context of inventory management as the selected research domain. The background section delineates the topic of inventory management, with a particular focus on online retail small to medium enterprises (SMEs) that oversee finished product inventory within a warehouse setting. It identifies the research gap this study seeks to address, presents the research aim and objectives, followed by an outline of the scope of this study and concludes with an overview of the thesis structure.

1.1 Background

Organisations hold inventory as an asset to sell to generate revenue, therefore, inventory management is recognised as one of the most critical business functions generating high financial performance (Nenes et al., 2010; Muchaendepi et al., 2019). Inventory management entails managing inventory received in the business, storing inventory, and then recording outbound inventory to fulfil customer demands. This covers managing physical inventory levels, storage, forecasting and replenishment of goods received, quality management and product returns (Sharma, 2016; Panigrahi et al., 2024). Inventory is a direct physical asset encompassing three components: raw materials, work-in-progress (WIP) and finished goods (Chalotra, 2018; Munyaka & Yadavalli, 2022). Raw materials are the goods in source material form. WIP refers to the goods being processed, manufactured or dispatched, and a finished product is ready for sale (Mor et al., 2021). Finished goods inventory can represent up to 50% of an organisation's total capital investment for distribution to the end customer (Munyaka & Yadavalli, 2022; Albayrak Unal et al., 2023). Organisations require accurate inventory data, and this is a significant problem, especially within the retail industry, where on average, 10% of profits are lost due to inaccurate inventory data (Tao et al., 2020; Vatumalae, 2022). Inventory management systems (IMS) help integrate, streamline, and automate inventory management processes (Vries, 2013; Eme et al., 2018).

Recent research within the inventory management field suggests that interest in inventory management and performance has been gaining momentum within the last 2 decades, showing that it is a growing field with its significance measured by the increase in publications (Kaur, 2023, Munyaka & Yadavalli, 2022). Munyaka & Yadavalli (2022) state that the publication of articles on the Science Direct publication database shows an increase of over 525% from the years 1998 to 2020. Panigrahi et al., (2024) suggest that the increase in publications in this field is due to the increasing competitor market, advancements in technologies used to aid in inventory management and complexities/challenges within inventory management.

Small to medium enterprises (SMEs) face critical inventory management challenges (Alam et al., 2024). SMEs do not have time, knowledge or resources to implement effective inventory management routines and practices (Wang, 2009; Narayanapillai, 2013; Kumar et al., 2015). This needs to be addressed as recent research highlights that SMEs do not consider appropriate inventory management techniques and overlook inaccurate inventory data and poor operational performance of the inventory management system, leading to significant monetary losses (Alam et al., 2024). This indicates challenges related to inaccurate inventory data are an issue for SMEs, and current research primarily focuses on technological solutions, such as tracking inventory using automated identification technology using either barcoding or radio frequency identification (RFID) (Alam et al., 2024).

Recent research from key authors such as Vries (2005, 2007, 2013 and 2020), Muchaendepi et al., (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) state that the causes of inaccurate inventory data are inter-related requiring a holistic socio-technical systems approach to improving inventory management systems. These authors emphasise that an IMS must be viewed holistically from both the technical and social perspectives, including processes, perceptions, attitudes, and behaviour of stakeholders involved and how both elements work in sync for an effectively operating IMS.

1.2 Research Question

Building on further from previous key authors in this research, the gap highlighted indicates that there is a lack of research on how a socio-technical approach can be adopted to improve data accuracy and address IMS challenges. Therefore, further research is needed to help SMEs take a holistic view of their inventory management system. This research proposes to address this gap by adopting a holistic socio-technical approach to improve the accuracy of inventory data for effective inventory management systems in SMEs. This research extends the work of Vries (2005, 2007, 2013 and 2020), Muchaendepi et al., (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) by exploring how a socio-technical system view of an IMS can be adopted to drive data quality improvements. The following research question has been proposed:

How can a socio-technical systems approach be adopted to improve inventory data quality?

1.3 Research Aim and Objectives

This research aims to improve data quality in inventory management systems in SMEs whilst adopting a socio-technical approach. To achieve this, this research proposes the following objectives:

- Develop a model of a socio-technical view of Inventory Management Systems
- Define challenges and critical success factors (CSF) in inventory management systems
- Validate challenges and critical success factors within SME organisations
- Develop a framework to improve data quality in inventory management systems
- Test and evaluate the framework in terms of its effectiveness in improving inventory data quality in inventory management systems

1.4 Research Scope

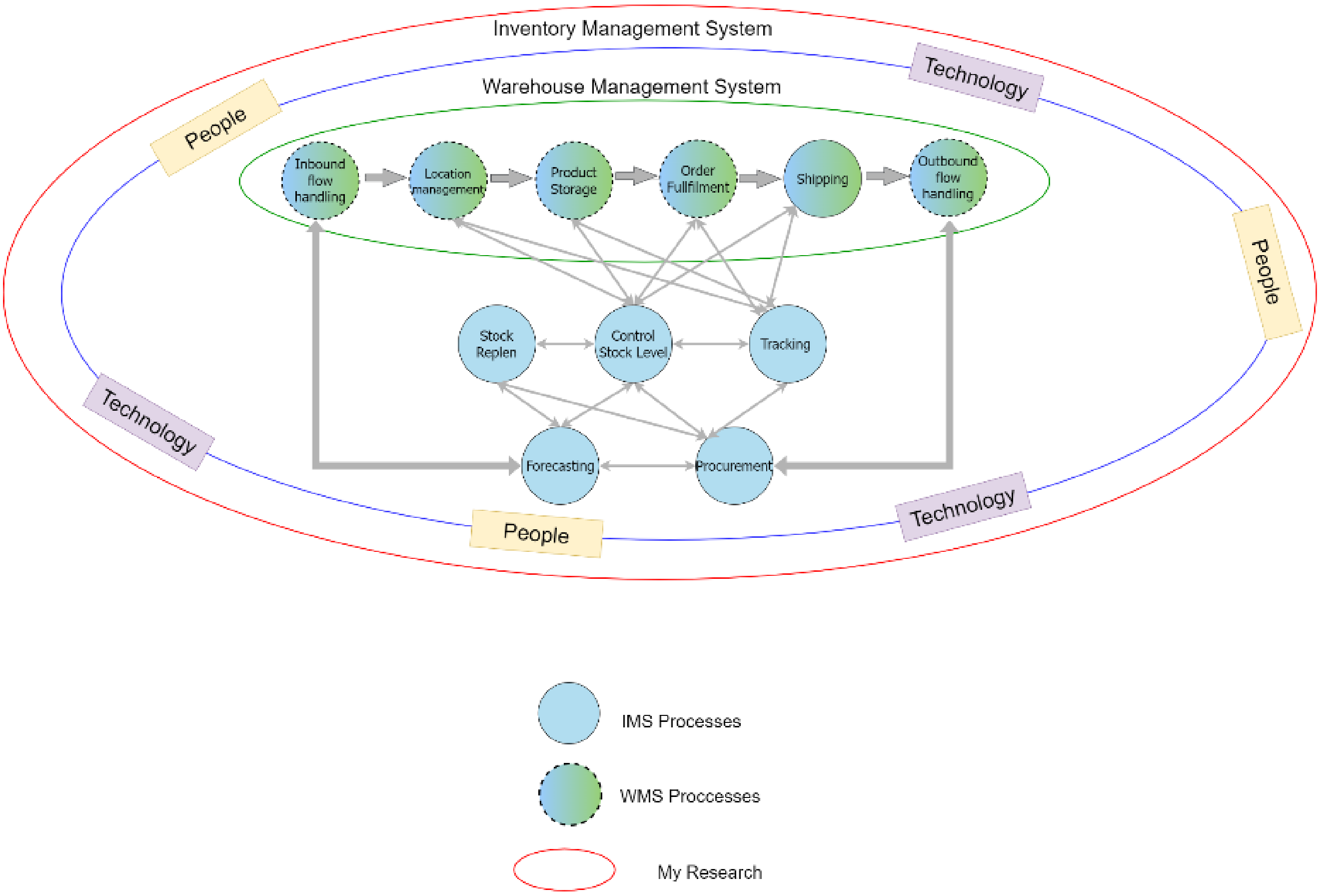

Figure 1 Research Scope

The scope of the research study is presented in Figure 1. In various studies, inventory management can also be referred to as warehouse management as inventory is stored within a warehouse environment (Rawat & Anusandhanika, 2015). The relationship between inventory management and warehouse management processes is visualised with a clear boundary in Figure 1. It illustrates the connection between inventory management systems and warehouse management systems (WMS), highlighting their interdependence and influence on each other's overall performance. Inventory management systems cover the scope of inbound to outbound logistics. Figure 1 shows both the inventory management and warehouse systems processes in the broken line circles with green and blue shading, indicating crossover within both areas showing the inter-relation of these two systems. The outer red circle highlights the scope of this research as it concerns all processes within the inventory management system.

Figure 1 displays IMS comprising of WMS as a subsystem, and 5 processes. Efficient inventory management plays a crucial role in the handling of inbound and outbound goods, leading to improved warehouse management (Alyahya et al., 2016; Vaka, 2024). Furthermore, Vatumalae (2022) states that an effective inventory management system enhances the efficiency and sustainability of warehouse operations, while an efficient warehouse management system enhances the accuracy of inventory management, demonstrating their direct interrelation. This research focuses on the inventory management of finished goods within a warehouse environment, as research shows that organisations are incurring financial losses due to inaccuracies and misplacement. An SME declared a yearly loss of £8-10,000, and another SME declared 5% of financial losses.

1.5 Overview of the Thesis Structure

The logical structure of the thesis is visualised in Figure 2. Chapter Two includes a literature review discussing the subject area of inventory management, the types of inventory management systems and the challenges of inventory management in SMEs. The literature review identifies critical success factors in inventory management systems and data quality measures needed to address inventory data quality that satisfy the second research objective. A socio-technical systems perspective of inventory management system is presented, and the challenges and CSF are categorised into organisational, people, process, and technology (OPPT) areas. It also discusses the existing technologies and software available for effective IMS performance. Chapter Two concludes with a conceptual model that conceptualises the literature findings, displaying the categorised challenges and critical success factors, looking at the relationships between these areas, and understanding how CSFs can help address the challenges. A model of a socio-technical view of inventory management systems is proposed.

Chapter Three focuses on the research methodology of this study, showing the adoption of interpretivist philosophy and the selection of a qualitative research approach. Chapter Four presents the primary data collection from inventory managers of 5 e-commerce retail SMEs in the West Midlands, UK, to validate the inventory management challenges and critical success factors from the literature findings in practice. This chapter analyses the data collected using Soft Systems Methodology (SSM) to help structure the problems of inventory management from the perspectives of different organisations, using rich picture analysis. This analysis helps validate the challenges and critical success factors derived from the literature. A root definition and a conceptual model are then developed to address the challenges identified.

Chapter Five discusses the design and development of a framework to improve inventory management systems within SMEs, implementing the conceptual model developed in Chapter Four. The literature on maturity models is discussed and methodologies for developing maturity models are evaluated. The design and development of a maturity model for inventory management systems, using the six-phase methodology of De Bruin et al., (2005) is documented. The development of a maturity index formula and definition of data quality measures is explained.

Chapter Six presents the case study to test and evaluate the framework using primary data collected from an SME to implement stages one and two of the framework. Refinements to the framework are documented. Recommendations to the SME are presented from stage 3 of the framework, and the impact on the SME is evaluated in terms of improvement to measurable impacts to maturity levels and improvements to data quality. Finally, Chapter Seven summarises the research study and its practical, theoretical and methodological contributions to knowledge. The thesis concludes with a discussion of the limitations and future research directions of the research within the inventory management systems field.

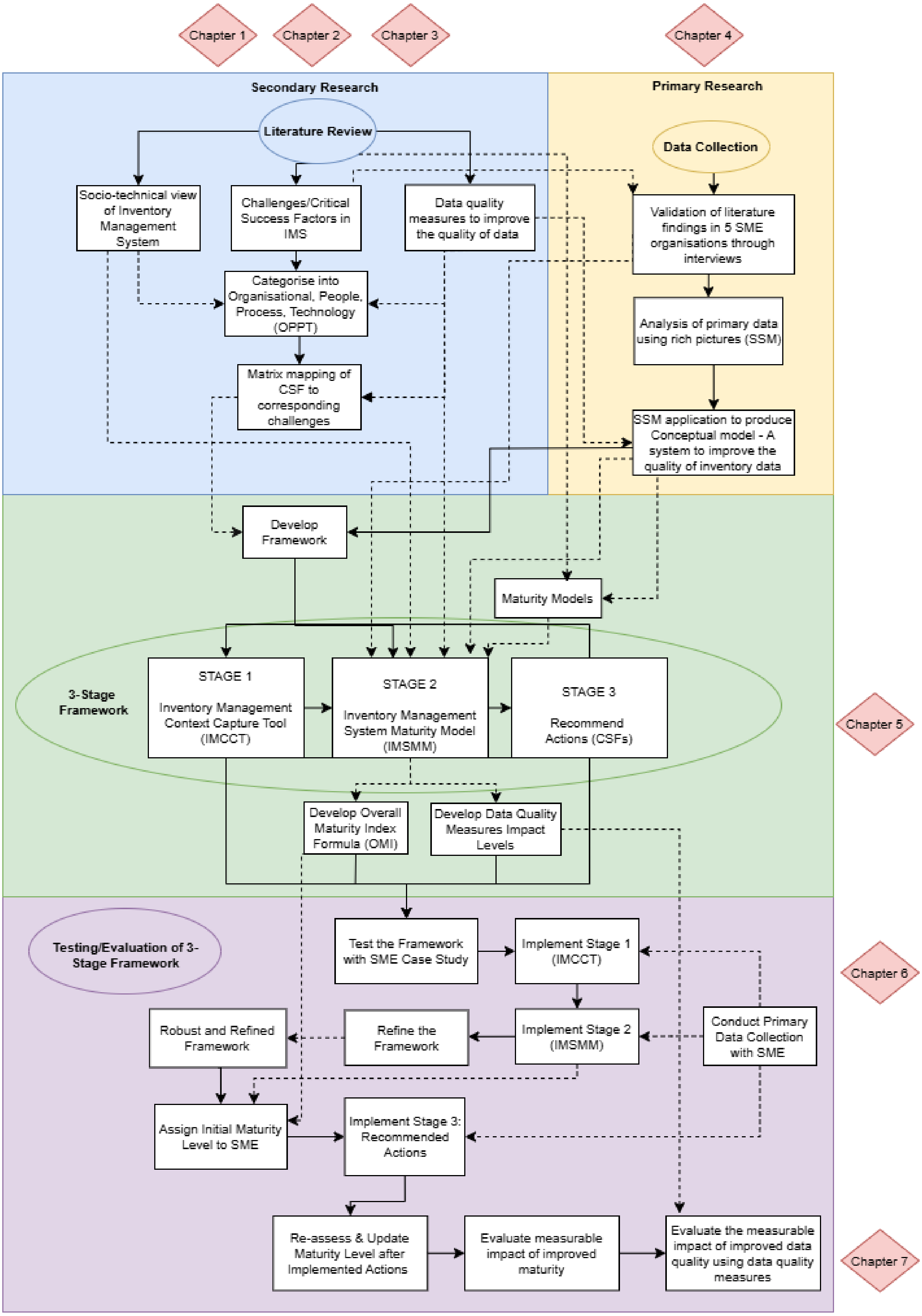

Figure 2 Logical Structure of Thesis

2 Literature Review

The purpose of this chapter is to present the literature review of inventory management, inventory management systems, including the challenges, critical success factors and existing technologies within inventory management systems to satisfy objective 2 of this research. The chapter concludes with a model of an inventory management system through a socio-technical lens to satisfy objective 1.

2.1 Inventory Management

Inventory is a direct physical asset that generates high financial performance (Muchaendepi et al., 2019). Sharma (2016) states that inventory management is crucial to business operations, to reduce monetary loss. Successful inventory management aims to improve customer service and satisfaction while keeping inventory costs low (Nemtajela & Mbohwa, 2017). Inventory management entails all the activities required to manage the inventory items effectively, and this includes receiving, storing, forecasting, replenishing, scheduling, managing quality, processing returns and defective inventory (Hemalatha & Annadurai, 2020; Panigrahi et al., 2024). There are different definitions of inventory management and Table 1 shows a collection of inventory management definitions.

Table 1 Inventory Management Definitions

Author/ Reference	***Inventory Management Definition***	***Key Points***
(Rawat and Anusandhanika 2015).	Inventory management concerns the fine lines between replenishment lead time, carrying costs of inventory, asset management, inventory forecasting, demand forecasting, inventory valuation, inventory visibility, physical inventory available space, quality management, replenishment, returns and defective goods.	• Carrying costs of inventory • Inventory and demand forecasting • Replenishment • Physical storage space
(Hemalatha & Annadurai, 2020)	Inventory management is the procurement and storage of inventory items to aid business operations.	• Procurement • Inventory storage

(Srinivas, 2022)	Inventory management is ensuring sufficient inventory is available to meet customer demand.	• Maintaining sufficient inventory levels • Meet customer demand
(Vatumalae, 2022)	Inventory management ensures smooth flow of inventory and maintained accurate inventory levels to meet the customer demand	• Maintain accurate inventory levels • Meet customer demand
(Munyaka & Yadavalli, 2022)	It is identified as the organisation, securing, storage, and distribution of the right materials, of the right quality, in the right quantity, in the right place and at the right time. Inventory management ensures a good balance between keeping the total cost of inventory minimal and maintaining a high customer satisfaction level.	• Inbound, storage to outbound inventory • Minimising inventory costs • Maintain high customer satisfaction
(Mashayekhy et al., 2022)	Managing inventory means minimising inventory costs by implementing the correct inventory replenishment policy to maximise customer service.	• Minimising inventory costs • Correctly replenishing inventory • Maintain high customer satisfaction/service
(Albayrak Unal et al., 2023)	IM is a continuous process of planning, organising, and controlling inventory, minimising cost and balancing supply/demand. It includes forecasting demand, management, shipping, physical space, quality management, returns, and defective goods.	• Organising inventory • Planning and controlling inventory • Forecasting • Shipping • Storage space
(Pramodhini et al., 2023)	Inventory management entails organising, planning, acting, controlling, and utilising resources and the overall inventory tracking from suppliers to warehouses to customers.	• Organising inventory • Planning and controlling inventory • Inventory tracking
Chaudhary et al, (2023)	Inventory management (IM) is a critical component of any business operation. It involves planning and controlling the inventory levels needed to meet customer demand. Effective IM can increase profitability, whereas poor IM can lead to lost sales, high costs, and reduced customer satisfaction.	• Controlling inventory levels • Meet customer demand • Increase profitability
(Kaur, 2023)	The overall function of inventory management is to supply the	• Supplying materials to meet customer demand

	material at the required place within the time limits.	
(Trajanova and Dimitrova, 2023)	Inventory management is maintaining inventory levels to determine the optimal inventory size to meet demand.	• Maintain sufficient inventory levels to meet the required inventory size • Meet demand
(Alam et al, 2024)	Inventory management is an organisation's building block. It is an essential part of decisions regarding inventory handling, following the correct policies and procedures, and ensuring a sufficient quantity of inventory to meet customer demand.	• Policies and procedures • Decision making • Meeting customer demand

Inventory management has multiple definitions, and these definitions vary across scholars, yet they all typically share the same fundamental meaning. The key common principles are maintaining accurate and sufficient inventory levels to meet customer demand, organising inventory in terms of physical storage space, replenishing inventory and avoiding high inventory costs. The definitions show that there is agreement that inventory management is focused on overseeing the core activities to ensure sufficient inventory levels are accurate and maintained to meet customer demand. However, these definitions differ as some definitions like by Alam et al., (2024) focus on underlining the use of policies and procedures to manage inventory and other definitions like Kaur (2023) focus on the supplying of materials within a required timeframe. Overall, it is noted that inventory management helps maintain accurate inventory levels, inform decision-making, initiate policies and procedures, and improve operational performance.

Authors	**Inventory Management Categories**									
	Forecasting	Replenishment	Inventory Storage/ Location	Procurement	Maintain Inventory Level	Fulfilment/ Shipping	Decision Making	Inventory Received	Minimising Inventory Cost	Tracking
(Rawat and Anusandhanika 2015).	•	•	•						•	
(Hemalatha & Annadurai, 2020)			•	•						
(Srinivas, 2022)					•	•				
(Vatumalae, 2022)					•	•				
(Munyaka & Yadavalli, 2022)		•	•	•	•	•		•	•	•
(Mashayekhy et al., 2022)		•							•	
(Albayrak Unal et al., 2023)	•	•	•		•	•				
(Pramodhini et al., 2023)			•							•
Chaudhary et al, (2023)					•	•				
(Kaur, 2023)				•		•		•		
(Trajanova and Dimitrova, 2023)					•	•				
(Alam et al, 2024)		•	•		•	•				

Table 2 Comparison of Inventory Management Definitions

Table 2 lists all the inventory management activities identified within the definitions from authors in Table 1. It visualises the agreement and differences in the inventory management definitions. The inventory management activities listed in Table 2, outline the scope of inventory management processes. The definitions outlined in Table 1 reflects the core view and fundamental principles of inventory management: receiving, storing, and shipping items to ensure that accurate inventory levels are maintained to fulfil customer demand. This table was used as the foundation for defining the research scope as presented in Chapter 2, Table 1.

Munyaka & Yadavalli (2022) outline the evolution of the concept of inventory management. Since ancient times, traders have always counted the items sold each day. The Egyptians and Greeks introduced inventory management through the manual recording of items sold. Panigrahi et al., (2024) explain that the formal study of inventory management as a field of management science began in the early 1990s. This was initiated with the work of Harris (1990), who developed the economic order quantity model (EOQ) to order the optimal quantity of inventory, reducing holding costs and thus improving the efficiency of inventory management. The next development shift found in late 1990s, was the emergence of computers and information technology. Manually handwritten records of inventory result in inaccuracies and are an inefficient practice, and computerised inventory management systems were introduced to reduce costs and improve the accuracy of data, leading to improved customer satisfaction (Munyaka & Yadavalli, 2022). Maintaining inventory levels is important to meet customer demand, and this requires different types of inventory to be managed efficiently. The following section outlines the two types of classifications of inventory that can be done.

2.1.1 Classification of Inventory

Inventory of finished goods is classified depending on demand, cost and efficiency, in order to effectively manage inventory levels. Classification of inventory can be done using ABC analysis or Fast moving, Slow moving and Non-moving (FSN) analysis and these are two distinct methods each serving different purposes and are based on different criteria. The ABC classification model prioritises inventory based on their values, demand, cost and stock levels for the purpose of prioritising inventory control efforts and improved decision making on re-ordering inventory. The benefits of using this classification are that it optimises working capital on high-impact items and reduces stock-outs and overstocking of critical items (Esmail Mohamed, 2024). This allows the organisation to prioritise their focus on certain items and allocate resources to the most critical items (Pramodhini et al., 2023). ABC analysis has 3 categories: Category A involves items that are the most profitable, category B involves 15% of the items that make up only 75% of the profit and category C involves 80% of the items that make up 20% of the profit (Trajanova & Dimitrova, 2023). Inventory in category A holds the highest level of importance and is most critical, requiring tight control and frequent counts, followed by category B with items needing medium-level monitoring, and finally, category C holding lesser significance and is the least critical and can be managed with less rigour.

FSN (fast, slow and non-moving) analysis enables improved decision-making regarding inventory locations. This is so that fast-moving items are easily accessible and can be monitored for accuracy, replenishment and resource allocation. FSN has 3 categories: Category F are items with a high consumption rate, category S are items that have a slow consumption rate, and category N are items with no consumption and are non-moving (Ali et al., 2023). It helps to identify inventory with a high consumption rate as well as the items that are just not moving at all. These classifications differ as the ABC analysis focuses on prioritising inventory items based on their value in terms of contribution to overall cost and its annual consumption rate, whereas FSN analysis focuses on the movement of inventory items from an operational efficiency perspective, based on their consumption and usage. This ensures that stock-outs can be avoided, and slow/non-moving inventory can be identified for possible reduction or disposal to increase storage space.

2.2 Inventory Management Systems

2.2.1 Overview

An inventory management system (IMS) is defined as a collective of rules, processes and controls that aid in detecting, managing and maintaining accurate inventory levels (Nemtajela & Mbohwa, 2017). Vries (2013) states that the role of an inventory management system is to integrate, streamline and automate some or all processes regarding the management of inventory data. Nemtajela & Mbohwa (2017) also agree that an important aspect of inventory management systems is to create, apply, and manage the correct processes and procedures involved. An inventory management system encompasses all inventory management activities as show in Table 2, including purchasing, shipping, receiving, tracking, storage in the warehouse, turnover, and re-ordering inventory (Eme et al., 2018). Al-Momani et al., (2020) and Vries (2013) states that inventory systems consist of planning and control elements within a physical, informational and social dimension in an organisation, considering the attitudes and interests of the stakeholders involved within the organisation. In addition, Pontius (2017) also describes an inventory management system as a combination of technology (based on hardware and software), processes and procedures overseeing the monitoring and maintenance of inventory. Crosby (2019) explains how some inventory management systems consist of software and technology working in a circular process of tracking, monitoring and replenishing inventory levels. Ali et al., (2023) explain an IMS as the matrix of technology, process and procedure that oversees the inventory control. Panigrahi et al., (2024) state that inventory management systems also consist of non-technological factors such as human resources, organisational and economic factors and behavioural aspects that all together also play a vital role in improving the operational performance of IMS.

Inventory management systems were facilitated through the ‘Industrial Revolution’ where the key focus of businesses had become mass production and customer experience at the point of sale showing how important it was to manage inventory effectively to ensure customer demand was met in a timely manner (Crosby, 2019). In the early 1990s, companies started developing inventory management software to record data as the stock was scanned in and out of warehouses to improve accuracy. This has since evolved into complex inventory management systems improving inventory level accuracy and operational efficiency. Organisations that do not utilise an IMS, risk problems such as high investments for inventory, poor inventory storage, stock-outs, inventory inaccuracy and difficulties in tracking inventory, all affecting organisational performance (Nyemba & Mbohwa, 2017). The success or failure of an organisation and its business operations relies on the performance of its IMS (Mor et al., 2021).

2.2.2 Beneficial Impact of Inventory Management Systems

The overarching benefit of inventory management systems is maintaining accurate inventory data and increasing the operational performance of inventory management (Eme et al., 2018). An inventory management system helps establish effective policies and controls that aid in monitoring inventory levels for replenishment to meet customer demand (Alam et al., 2024). Wei & Razali (2023) state that IMS provides better control and handling of inventory, which helps to maintain accurate inventory levels, reducing errors. Inventory management systems improve how inventory is managed in a range of industries, such as food manufacturing and healthcare. In the food industry, fresh and frozen food products require special handling due to their shorter shelf life, so without effective inventory management systems, foods would have a high probability of spoilage (Liang, 2013). An IMS ensures that food inventory is maintained to reduce instances of spoilage and addresses food-related, process-related, and operation-related factors for effective inventory management. Within the healthcare industry around pharmaceuticals, IMS allows the pharmacies to adequately manage the flow of drugs in the store and reduce the risks of being understocked, which could disrupt operations and lead to endangering patients (Eme et al., 2018). Discrepancies in medicinal inventory could result in stock-outs, causing safety concerns and danger to patients, thus emphasising how IMS are crucial for maintaining efficient operational performance. As with other industries mentioned, the relief logistics sector for humanitarian relief operations also uses IMS to manage the inventory of relief supplies in a timely manner in such vulnerable conditions (Beamon & Kotleba, 2006). This highlights how IMS can enhance overall operational performance and positively impact society.

IMS can be categorised as being paper-based/manual, automated, or enterprise resource planning system (ERP)/ integrated systems, software packages. The following sections discuss these categories.

2.2.3 Manual Inventory Management Systems

Some organisations use manual inventory management systems comprising of paper-based systems, Excel spreadsheets or document management applications. Although manual processing of inventory information works well, this increases the risk of data inaccuracies, resulting in impaired decision-making overall, impacting negatively on company profits and performance (Kittisak, 2023; Salih et al., 2023). These systems are costly and resource-intensive and are not the most appropriate inventory management approach (Mathaba et al., 2011).

2.2.4 Automated Inventory Management Systems

Traditional manual inventory management systems, which rely on books, ledgers and spreadsheets for updating and checking inventory records are proven to have limitations and work inefficiently (Chai et al., 2023; Wei & Razali, 2023). An inefficient IMS can cause business risk by increasing instances of inaccuracies, leading to stockouts and customer dissatisfaction (Wei & Razali, 2023). Automated IMS can help automate manual tasks such as tracking inventory levels, low stock alerts, purchasing, re-ordering and generating reports on demand. Automation saves time, and reduces errors (Rodriguez & Obed, 2023). Salih et al., (2023) state that automated inventory management systems help improve the efficiency and accuracy of inventory management, resulting in effective operational performance. Automating some processes within an IMS, for example, the inventory re-order point, can help to assist supplier relationships and increase warehouse efficiency through real-time monitoring and timely re-ordering of inventory. This improves decision-making within the company (Amirrudin et al., 2023).

Large organisations typically adopt automated IMS; however, many SMEs still use paper-based and stand-alone systems. This is due to SMEs lacking the knowledge, awareness and resources to fully utilise automated inventory management systems to benefit from accurate inventory management (Sivasubramanian et al., 2017). Automated IMS can comprise of perpetual IMS, periodic IMS or an integrated IMS (Rawat & Anusandhanika, 2015; Garg & Kuhl, 2017).

2.2.4.1 Perpetual and Periodic Inventory Management Systems

A periodic inventory management system is where inventory is physically counted and updated as required on a specific date. A perpetual inventory management system differs as the inventory is automatically updated when the inventory is received or shipped (Rawat & Anusandhanika, 2015). Nemtajela & Mbohwa (2017) explain how perpetual and periodic systems differ, highlighting a key point that in a perpetual system, an order is automatically placed for stock each time the inventory reaches that re-order point. In a periodic review system, an order is placed for stock after a fixed time interval when counted as required.

2.2.4.2 Integrated Inventory Management Systems

An integrated IMS is integrated within existing systems, such as Enterprise Resource Planning (ERP) systems at the organisation (see Figure 3). This can consist of automated links to warehouse management systems (WMS) and logistics management systems (LMS). However, some integrated IMS are like ‘bolt-on’ software packages containing different inventory management modules within a toolkit, which can then be connected to the current ERP system (Rawat & Anusandhanika, 2015). The software packages can help in the addition and subtraction of stock as it is received or shipped and includes forecasts and report generation, however the software packages can be limited in their functionality (Sayer, 2018). An integrated inventory management system assists businesses in automating operations as well as improving their business processes so that these processes can provide maximum benefit for business performance (Bhatt, 2000). Organisations have made significant investments into integrated systems, which have resulted in more robust functionality, streamlined processes and improved communication within an organisational setting (Vries, 2013). The next section details the domain of warehouse management and its relationship with inventory management.

2.3 Warehouse Management

A warehouse is a building used for storing and buffering goods that arrive from suppliers for commercial purposes (Lopes et al., 2021; Van Geest et al., 2021). Vatumalae (2022) states that warehouse management is labour intensive and consists of: inbound flow handling, order-to-stock allocation, order batching and release, order picking, packing, and shipping. These activities are presented in Chapter 1, Figure 1. The purpose of warehouse management is to ensure that all warehouse activities are efficiently and effectively coordinated (Harmon, 1993). Effective warehouse management results in high operational efficiency in fulfilling orders to meet customer demands in a timely manner (Lopes et al., 2021; Van Geest et al., 2021).

2.3.1 Types of Warehouses

There are various types of warehouses with respective advantages as described by iThink Logistics (2021) and these are presented in Table 3 with a short description. To understand the type of warehouse required for an organisation, it is important to consider business needs, target audience, budget and supply chain.

Table 3 Type of warehouses (Source: iThink Logistics, 2021))

Type	*Description*
Public	In public warehouses, the storage spaces are rented out to the public and are run by a public authority. Can be owned by individuals and must adhere to the rules and be fully licensed to function.
Private	Owned by manufacturers or vendors who need entire warehouse space for their inventory. Mostly aimed at businesses due to the higher cost. As it is owned privately the inventory can be stored for however long needed until shipped.
Government	Owned and managed by central government with better safety and security of inventory. Both government and confidential parties may use to store their inventory. They are considered public warehouses as the government owns them. Rent and charges will be prescribed by the government if space is acquired.
Reinforced/ Bonded	Government and confidential offices own and manage this warehouse, which stores imported inventory for which customs have yet to be paid. Shippers are not able to move products until import obligations are paid.
Co-usable	Can be possessed by multiple companies constrained by co-employable social orders in agreement to work together to share the space.
Smart	Processes in storage, fulfilment, and management are controlled using automated artificial intelligence (AI), including automated and interconnected technologies in software and systems. Large organisations such as Amazon and Alibaba use smart warehouses to reduce errors.
Consolidated	It consists of a third-party storage facility and is strategically demand-driven. Small shipments from different sellers who want to deliver to the same destination are loaded into a single truck.
Cooperative	Owned and managed by cooperative societies at lower rates. The purpose is to drive profits and help their members.
Distribution warehouse/Fulfilment Centre	Has a larger space and enables the fast movement of large quantities of inventory. Goods are purchased and stored from different suppliers and then redistributed (sold) to wholesalers/retailers or consumers directly. A distribution warehouse can also be referred to as a fulfilment centre, which handles all processes from inbound to outbound logistics. A distribution centre is customer-centric and is the bridge between a supplier and its customers.
Cold Storage	Stored inventory at a regulated temperature suitable to the inventory requirements.

Production	Used for the storage of raw materials, semi-finished products where production results in finished products.
Contract	A contract warehouse is a third party logistics (3PL) storage facility that stored goods on behalf of a client.

The type of warehouse that this research focuses on is a distribution warehouse dealing with inventory of finished goods. These warehouses implement the inventory management system activities as presented in Chapter 1, Figure 1. The focus within a distribution warehouse, is to ship finished good inventory products to the end consumers which can be retailers, wholesalers, or end users (Srinivas, 2022).

2.3.2 Warehouse Management Systems

A warehouse management system (WMS) combines all warehouse and inventory activities and is supported by other systems, such as an inventory management system (Van Geest et al., 2021; Vatumalae, 2022) as presented in Chapter 1, Figure 1. It is designed to help reduce costs by automating warehouse functions and controlling the movement and storage of products (Ramaa et al., 2012). A WMS helps improve the efficiency of the warehouse and warehouse environment by ensuring inventory accuracy when dealing with inventory flow (Atieh et al., 2016; Tejesh et al., 2018; Ramaa et al., 2012).

2.3.3 Relationship between Inventory Management and Warehouse Management

There is a tight link between inventory and warehouse management, as warehouse management results in manageable inventory as shown in Chapter 1, Figure 1. Richard (2014) states that effective warehouse management contributes to inventory management and provides the following benefits: real-time stock visibility and traceability, accurate stock level, reduction in mis-picks and enabling perpetual inventory. Similarly, effective inventory management contributes to warehouse management by reducing inventory costs, maintaining accurate inventory levels, and ensuring inventory is stored and organised, resulting in efficient order-fulfilment operations (Fichtinger et al., 2015). As warehouses are premises responsible for housing the inventory, structure and layout are vital and contribute heavily to best practices of inventory management. Zhang (2017) states that enhancing the utilisation of space in the warehouse can positively impact inventory storage, resulting in improved productivity levels in warehouse operations and controlling inventory flow to fulfil customer demand. Overall, efficient and effective inventory and warehouse management improves all operations, resulting in significant tangible benefits such as inventory data accuracy (Piramuthu, 2013; Wang et al., 2016).

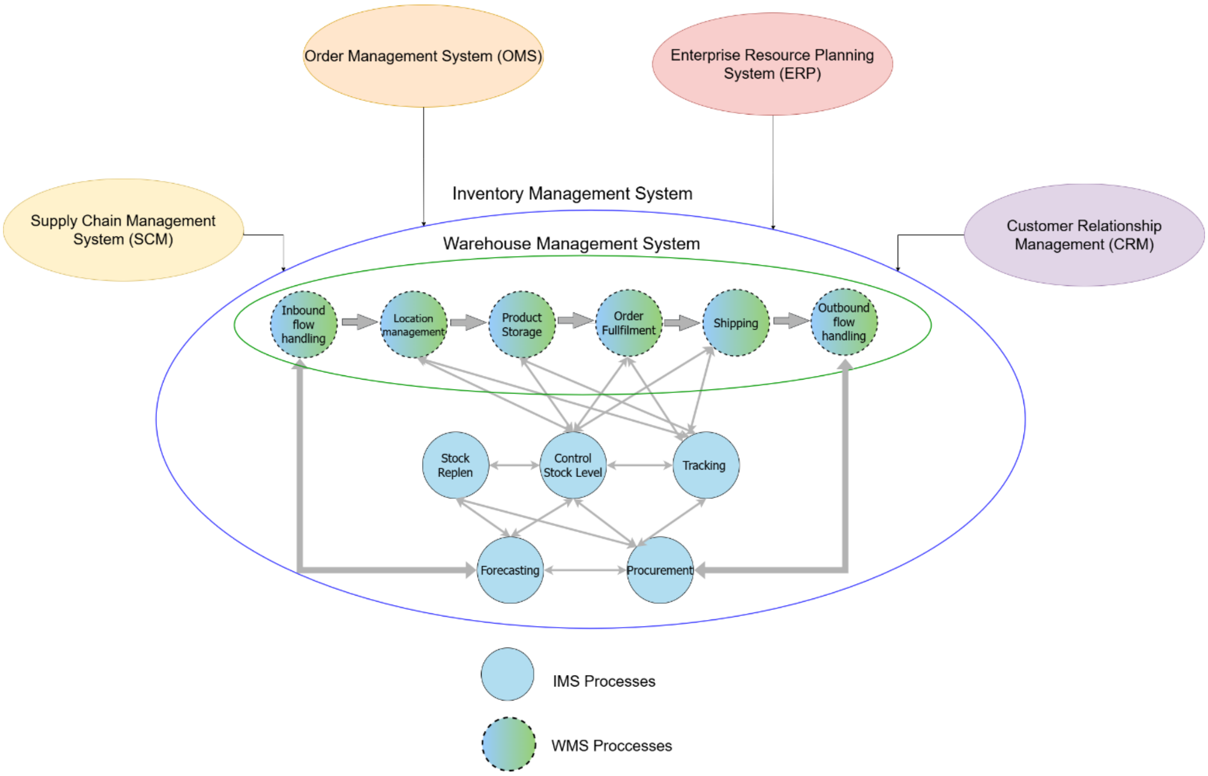

Figure 3 IMS and WMS Links with Other Key Systems

Figure 3 outlines the inventory management system and warehouse management system processes, showing links and relations from the IMS to potential other systems within the organisation such as customer relationship management system (CRM), order management system (OMS), Enterprise Resource Planning (ERP) and Supplier Chain Management System (SCM). The next section of the literature review discusses the challenges faced, critical success factors of inventory management systems, and existing technologies in place to aid in effective IMS.

2.4 E-commerce Retail and Its Inventory Management

E-commerce retail is the “trading of goods or services over computer networks such as the Internet” using mobile apps or other electronic devices, resulting in electronic transactions (Gahlot, 2019; Tolstoy et al., 2021). E-commerce retailers use distribution warehouses to manage inventory operations such as receiving and storing goods, order fulfilment and shipping of finished goods so that customers' orders placed online can be picked, packed and delivered within a timeframe (Fichtinger et al., 2015; Zhang et al., 2017; Boysen et al., 2019). Due to the importance of meeting customers' needs, warehouses are required to better respond to customer orders by fulfilling demand on time, and by meeting their expectations and promises of quick dispatch and delivery (Lopes et al., 2021; Van Geest et al., 2021). The core difference in inventory management between e-commerce retailers and retailers with physical stores is that in brick-and-mortar stores, inventory is held and directly available for customers to physically touch, and purchase (Zhang et al., 2017).

Inventory management is a difficult problem for e-commerce retailers (Darshan et al., 2023). The common concerns are that orders can be misunderstood, dead stock (inventory that is not expected to sell) issues, inaccurate inventory levels impacting fulfilment and poor inventory storage within the warehouse (Pramodhini et al., 2023). Specifically, in the retail industry, effective inventory management is critical to ensure that customers' demands are met, and that inventory is readily available whilst also minimising costs to the business, for example, costs of holding excess inventory etc. (Chaudhary et al., 2023).

2.4.1 SMEs – Small to Medium Enterprises and Its Inventory Management Challenges

An SME is a small to medium enterprise (The European Commission, 2019). The main factors determining an SME are staff headcount which must be less than 250 and turnover making less than or equal to 50 million. SMEs are well-recognised for expanding economic growth and play an important role in increasing productivity and efficiency in developing the national economy (Winter et al., 2009).

Inventory management is a vital requirement for SMEs and can help ensure inventory accuracy levels and ease demand forecasting to ensure inventory availability (Pramodhini et al., 2023). To ensure financial soundness, SMEs can implement effective inventory management practices (Alam et al., 2024). SMEs differ to large organisations in terms of their inventory management as Sivasubramanian et al., (2017) and Madhavi & Silva (2023) explain how SMEs lack knowledge and awareness of IMS and have constraints on resources in technology adoption.

SMEs do not consider inventory management as important as large organisations; therefore, they are faced with several challenges (Wang, 2009; Narayanapillai, 2013). Recent research highlights that SMEs neglect appropriate inventory management, leading to the inability to accurately manage the inventory flow (Munyaka & Yadavalli, 2022; Alam et al., 2024). Many SMEs tend to adhere to inventory management practices ineffectively based on pure intuition and lack professional knowledge, leading to inventory issues such as inaccuracies and other significant impacts on the company overall (Alam et al., 2024). Even though some SMEs understand the importance of inventory management practices, they still rely on traditional heuristics rather than the modern practices available (Panigrahi et al., 2024). Many SMEs use manual inventory management systems, either paper-based or a spreadsheet, to manually track inventory levels, which is effective based on the SME and its requirements; however, can be prone to errors and inaccuracies (Wei & Razali, 2023). With technology's evolution and gradual adoption, SMEs can now find affordable inventory management software and systems to improve their business operations (Eme et al., 2018; Muchaendepi et al., 2019). Technology enables SMEs to manage operations to increase productivity levels effectively (Winter et al., 2009). Inventory management within SMEs is therefore crucial and actively contributes to a better and improved inventory management system overall (Munyaka & Yadavalli, 2022).

In relation to IMS challenges faced within SMEs, key authors such as Vries (2005, 2007, 2013 and 2020), Muchaendepi et al., (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) state that the causes of these challenges are inter-related, meaning technology related issues can result and impact people or process issues and vice versa. Both Vries (2007,2013,2020) and Winkelhause & Grosse (2022) emphasise the view that there are not only technical aspects of an IMS but also social aspects such as processes, perceptions, attitudes, behaviour and communication of stakeholders involved and how both the technical and social aspects interact together. They share the view that humans play a significant role within all warehouse and inventory management operations and that technology should not be the only element considered when looking to increase efficiency in inventory management. Vries (2020), argues that the reason for inventory management problems is due to the ongoing issue of organisations failing to view an IMS from both a technical and social perspective to improve its operational performance. Muchaendepi et al., (2019) further strengthens this argument stating that challenges such as miscommunication between people sharing information, and issues with people ineffectively using technological systems, are causes of inaccurate inventory data. All key authors emphasise that an IMS must be viewed holistically from both the technical and social elements, working in sync to manage inventory data effectively. The following section details socio-technical systems theory, which underpins the interrelation of social and technical elements in a system and outlines the holistic approach adopted in this research to improve inventory data quality and operational performance of IMS.

2.5 Socio-Technical Systems (STS)

The term socio-technical system (STS) was originally coined by Frederick Emery and Eric Trist (1950). It involves social and technical elements in a system, consisting of interactions with humans, machines, and environmental aspects of the work system. Emery and Trist (1978) introduced socio-technical system theory to address the interplay and interaction between social and technical elements within an organisation. The theory was grounded in a key principle that STS can improve work system performance by considering the system's social and technical aspects. They argued that to achieve optimal organisational performance, a balance of the social and technical elements is required. Emery & Trist (1978) emphasise this principle as the concept of joint optimisation in their work on socio-technical systems. Joint optimisation emphasises the interrelation and equal consideration of both the social and technical elements, highlighting that the effective performance of a system depends on the harmonious interaction between technology and the people operating it. A more recent definition of socio-technical systems is given by Sony (2020), defining STS as an abstract interaction between people, processes and technologies to deliver the required output, further showing the consistent evolution of the socio-technical systems theory. The following section explores the history and evolution of socio-technical systems theory from the early 1950's to early 2000's.

2.5.1 History of STS

Socio-technical systems (STS) were identified in the 1950s when the introduction of new technology did not invariably lead to enhanced performance and productivity in organisations (Oosthuizen, 2016). STS originated during the coal mining in post- war reconstruction, where despite major investments in increased mechanisation, coal mining productivity was failing. Emery and Trist revolutionised the industry by showing that technical efficiency alone does not guarantee productivity, and that an integrated approach addressing both social and technical elements would optimise productivity. At the time to resolve this, they aligned the mechanisation with the human dynamics through autonomous workgroups of miners, empowering workgroups to make decisions thus minimising down time, recovery of group cohesion and redesigning workflows to complement technical systems with human skills and capabilities (Trist, 1981). This resulted in enhanced worker satisfaction, reduced absenteeism and improved productivity and efficiency (Trist, 1981). The philosophy of STS, which embraces the joint optimisation of both technical and social elements in systems, has proven to be practical and relevant. Acceptance and recognition have been increasing, contributing to the evolution of STS thinking and practice (Davis et al., 2014). Figure 4 shows the evolution of socio-technical systems starting from the early 1950's to the early 2000's.

Figure 4 Evolution of Socio-technical Systems (Based on: Painter, (2009)

2.5.2 Purpose of STS

The overarching purpose of socio-technical systems is to develop systems that address the interplay between social and technical elements, ensuring they work together in joint optimisation to enhance efficiency, adaptability and productivity as emphasised by Emery & Trist (1950). In addition, STS allows for a better understanding of how human, social and organisational factors affect the ways that technical systems are used. This can contribute towards the successful design of organisational structures, business processes and technical systems with a human-centred focus (Baxter, 2011). Adopting a socio-technical approach to system development results in more acceptable systems to end users delivering better value to stakeholders (Baxter, 2011). Oosthuizen (2016) states that socio-technical systems are in place for humans to use technology with the aim of increasing adaptability and fostering human-centred work environments. Only technology focused approaches do not properly consider the complex relationships between the people, organisation, business processes and the system supporting these processes (Baxter, 2011). Failure to adopt socio-technical approaches can increase the risks of systems being unable to provide maximum performance in achieving organisational goals (Baxter, 2011).

The following characteristics of socio-technical systems are foundational for designing, implementing and managing systems that balance the social and technical elements to achieve organisational goals (Baxter, 2011):

- Systems should have interdependent parts
- Systems should be able to adapt and pursue goals in external environments
- Systems comprise of interdependent technical and social sub-systems
- Systems have equifinality where system goals can be achieved by more than one means
- Systems performance relies on joint optimisation of the social and technical elements

2.5.3 Existing STS Frameworks

Over the past years, several STS frameworks have been developed to guide the design, analysis and joint optimisation of systems. This section explains the existing STS frameworks by Leavitt's Diamond (1965), Bostrom & Heinen (1977), Davis et al, (2014) and Chai (2012).

2.5.3.1 Leavitt's Diamond (1965)

Harold Leavitt created a framework named Leavitt's diamond in 1965, as presented in Figure 5 Leavitt's (1965) socio-technical framework was developed focusing on the relationships between four interdependent variables - people, tasks, structures and technologies. The framework analyses the organisation-wide effects a change strategy can have, and Leavitt (1965) argued that in order for change to be successful, it is crucial to understand the connection and interrelatedness between each element. Leavitt's (1965) diamond postulates that it is rare for organisational changes to occur in isolation. Therefore, this framework emphasises the need for the interrelatedness of these components so that any change made in any one element, usually results in compensatory or retaliatory change in the others (Okunoye, 2003).

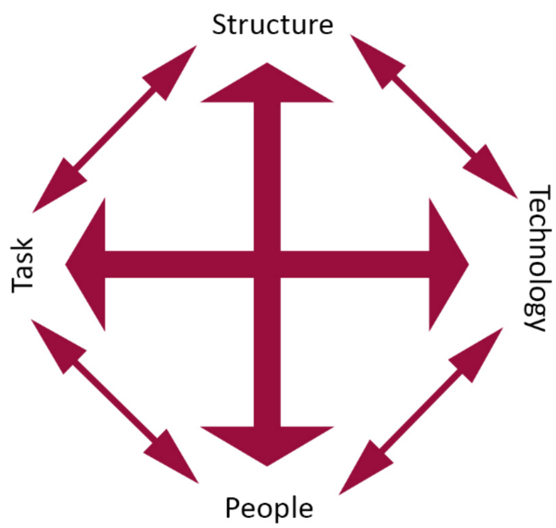

Figure 5 Leavitt's Diamond (1965)

2.5.3.2 Bostrom & Heinen (1977)

A socio-technical system consists of both social and technical sub-systems as defined by Bostrom & Heinen (1977). Elements within the social system include organisational structure and people. The technical system includes elements such as the physical system (hardware, software and facilities) and the task (work) which can be known as work processes. This framework depicts how each of the elements are interrelated, in terms of presenting that people work in the organisation and use the technological artefacts (tools, devices, techniques) to complete tasks/ follow processes, all within a complex work environment (Oosthuizen, 2016). The Bostrom & Heinen (1977) framework builds on Leavitt's diamond by exploring the wider environment in which it is situated, and is presented in Figure 6.

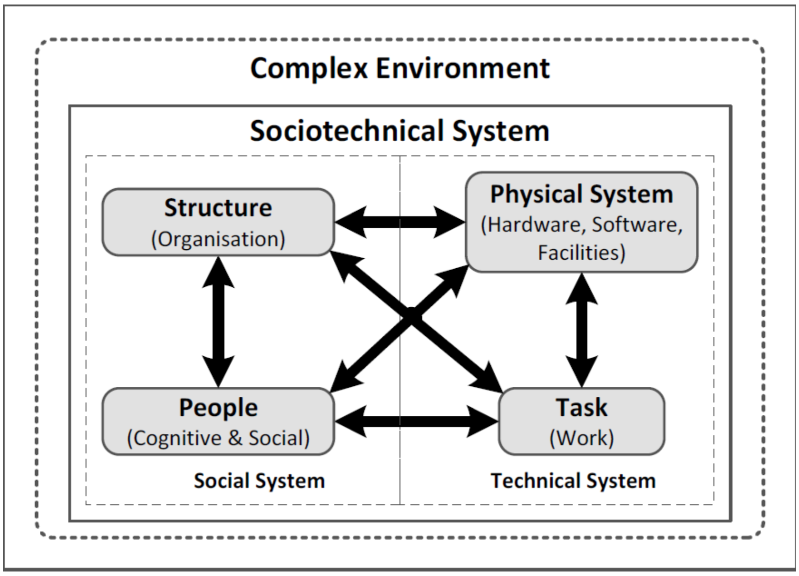

Figure 6 Bostrom & Heinen's (1977) model of Socio-technical system (STS) (Source: Bostrom & Heinen, 1977)

2.5.3.3 Davis et al., (2014)

Davis et al., (2014) define STS as humans applying and using technology to perform work through a process within an organisation (social structure) to achieve a goal. Leavitt's diamond (1965), the socio-technical framework, has been further extended by Davis et al., (2014) through action research and case study analysis to represent an organisational system using six interrelated elements embedded into an external environment as shown in Figure 7. Davis et al., (2014) explores the work system having a set of goals/metrics which involve people (different attitudes and skills). Davis et al., (2014) suggest that people will be using a range of tools and technologies, working in a physical environment, following cultural guidelines and following processes and work practices. This system sits within the external environment which consists of a regulatory framework, stakeholders and financial circumstances impacting overall (Davis et al., 2014). The extended STS framework provides a simple yet powerful representation of the independent variables of work systems and analyses the several linkages and relationships between the social and technical aspects. Davis et al.,

(2014) argue that to advance socio-technical systems thinking, the conceptualisation of what is meant by systems should be extended as well as widen the application domains.

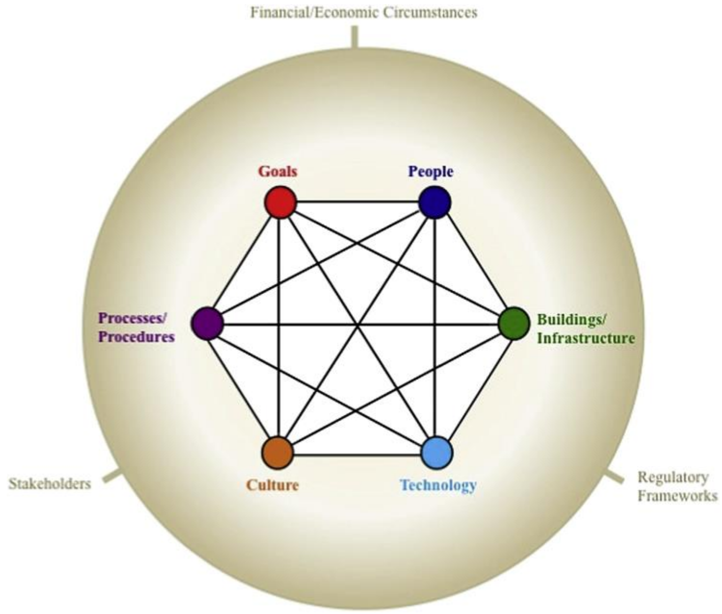

Figure 7 Socio-technical system illustrating the interrelated nature of an organisational system, embedded within an external environment (Source: Davis et al., 2014)

2.5.3.4 Chai (2012)

Chai (2012) defines a socio-technical system as comprising two sub-systems. The technical subsystem focuses on the processes, tasks and technologies used for output, whereas the social subsystem focuses on the people relationships and attributes including attitudes, behaviours, skills and communication. A socio-technical system provides a useful framework to understand how technology is adopted and used within an organisation (Chai 2012), which is important when implementing or changing technical systems (Chai, 2012; Sony, 2020).

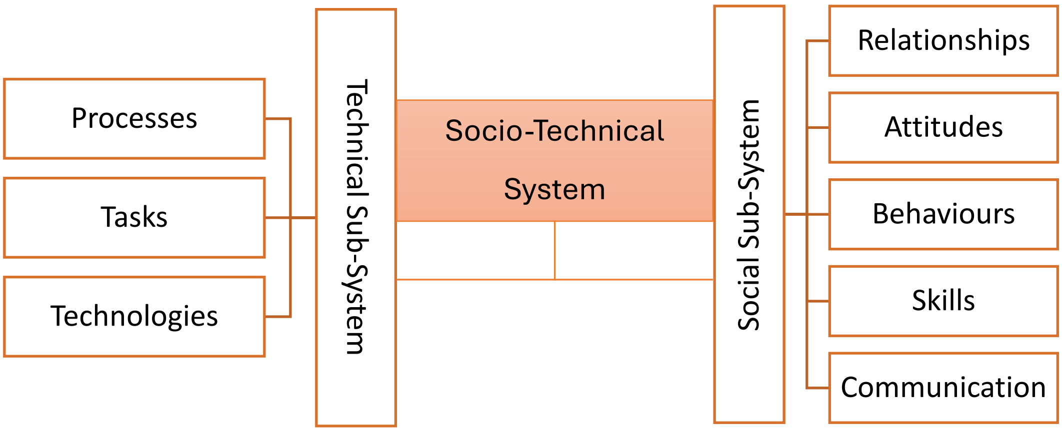

Figure 8 STS Framework (Based on: Chai, 2012)

Socio-technical systems frameworks have been developed over time to address different areas of research. Each framework reflects the perspectives and contextual basis of researchers at the time of its development. It is noted that there is some variability amongst them, however, they still capture the core view of the interrelation among social and technical elements. All frameworks discussed emphasise the interdependence of elements, highlighting the need for joint optimisation and further adapting the socio-technical principles to their specific context analysed within each author's work. Some authors have additional elements as part of their framework, and some have further extended the foundational basis of socio-technical system, such as Davis et al., (2014,), Leavitts Diamond (1965) and Bostrom & Heinen (1977) with the incorporation of organisational structure, task and culture. Davis et al. (2014), in particular, focus more on aligning people and technology with other elements such as organisational culture, processes, goals and infrastructure. Notably, Bostrom and Heinen's framework further breaks down each of the main elements discussed, providing a small description to explain the element in detail such as the physical system entails hardware, software and facilities. Similarly, Chai (2012) further interpreted the socio-technical system within the context of information systems. It dissects the social and technical elements, providing sub-elements for increased detail and clarity.

The emergence of frameworks collectively drives the application of STS theory, offering practical interpretations and emphasising the joint optimisation of the social and technical elements for varied contexts, industries and problems. The frameworks also enable researchers to compare and contrast the approaches, helping to deepen the understanding of the interrelation between social and technical elements.

2.5.4 Uses of Socio-Technical Systems Theory: A Socio-Technical Approach

The ETHICS methodology is an important STS approach that was introduced by Enid Mumford in 1995 to help improve the integration of technology in organisations. ETHICS is the acronym for 'Effective Technical and Human Implementation of Computer- based Systems' (Mumford, 1995). ETHICS methodology echoes STS in establishing a way to design systems that recognise the interaction of people, technology and procedures, to produce technically efficient work systems that have social aspects leading to high job satisfaction (Mumford, 1995). The methodology originally consisted of 7 stages and was further expanded to 15 stages to take into consideration additional issues when systems have been introduced, exploring that new technology can also be thought of as a human issue. Leitch & Warren (2010) explain that initial research prior to developing the ETHICS methodology investigated the impact on the use of computers on individuals within the organisation, including job role changes, perceptions, behaviour, needs, expectations and job satisfaction, defining a 'good fit'. This resulted in the key research finding *"If a technical system is created at the expense of a social system, the results obtained will be sub-optimal"* (Leitch & Warren, 2010). ETHICS emphasises the alignment of technology with the needs and values of the people and organisation involved to further manage organisational change. This methodology comes with the view that for a system to be effective, the technology must closely fit with the social and organisational factors, highly focusing on improved quality of work life and job satisfaction in a system design process.

2.5.5 Theoretical Perspective

The theoretical perspective of socio-technical systems is rooted in the idea that organisations are complex systems comprising two interdependent sub systems (Coiera, 2007). The social system includes people who implement work tasks as well as relationships and communication structures within the work environment. The technology system focuses on the process, tasks and technology which is required to convert the input into the desired output (Oosthuizen, 2016). It explores the fact that people's willingness to adopt a system/technology is modified by the social, behavioural and attitudes of the people involved. The socio-technical theoretical perspective emphasises that social and technical elements must work in joint optimisation to result in effective organisational performance further underlining the fundamental premises of STS theory as stated by Emery & Trist (1978) and Fok et al., (1987). Collating the research on STS, STS frameworks and approaches from previous sections, key points can be summarised as:

- Joint Optimisation
- Interdependence
- Holism
- Systems Thinking
- Human-Centered Design
- Organisational Change
- Adaptability

2.5.6 Rationale for Adopting a Socio-Technical Systems Approach

The preliminary literature review in Chapter 1 identified a research gap: the factors that affect the quality of inventory management systems are complex and interrelated and are often examined independently. Key authors such as Vries (2005, 2007, 2013 and 2020), Muchaendepi et al., (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) emphasise that an IMS must be viewed from both the technical and social perspectives for effective operational performance. This necessitates a holistic socio-technical systems approach to improve inventory management and enhance inventory management systems in this study.

After analysing several socio-technical systems frameworks in Section 2.5.3, four key elements were identified as being core to socio-technical systems and were therefore adopted as the socio-technical approach used within this research:

- Organisation (O) – Represents structure, strategy, policy
- People (P) – Represents skills, behaviours, communication and attitudes
- Process (P) – Represents process integration, alignment and implementation
- Technology (T)– Represents the type of technology, automation, adoption and technology integration

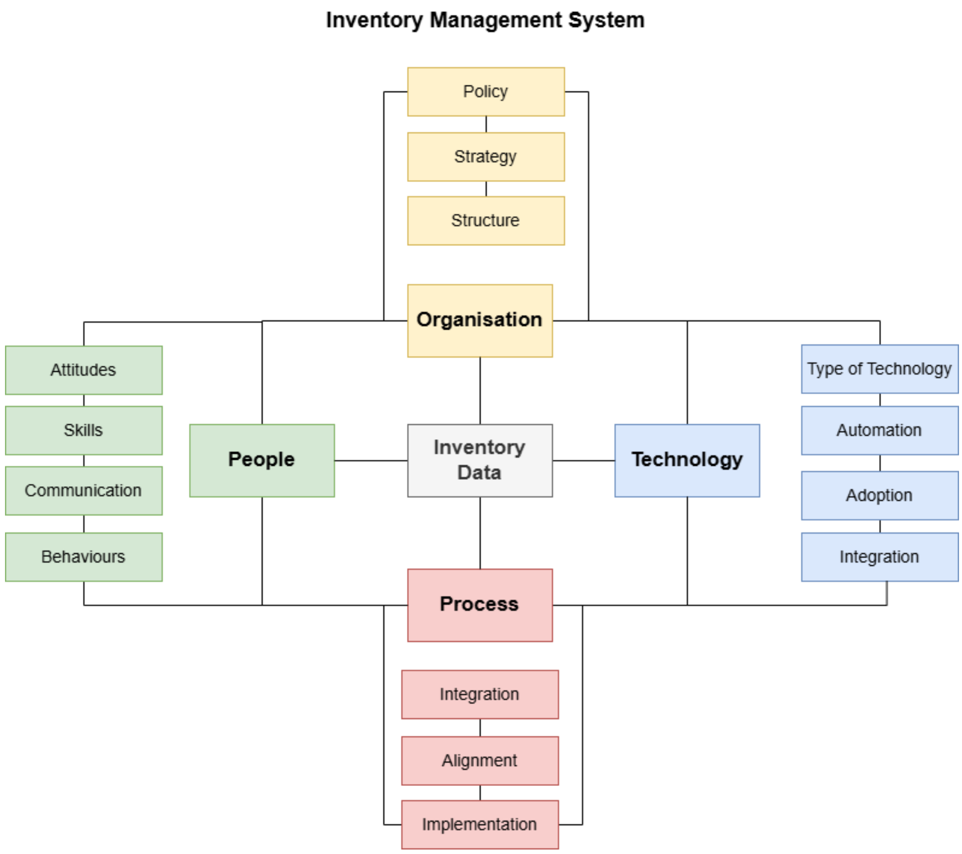

Figure 9 Socio-Technical View of Inventory Management Systems

The approach to selecting the elements of OPPT has been outlined in this section. This, therefore, informed the socio-technical lens required to view an inventory management system as a socio-technical system reflecting those elements as shown in Figure 9. This selection of elements forms the approach of OPPT and emphasises the synergy between the social and technical elements and their interrelatedness, ensuring joint optimisation. Figure 9 was informed by Chai (2012)'s STS framework where processes and technologies are part of the technical sub-system and attitudes, skills, behaviours and communication are part of the social sub-system. The people and technology elements were selected from Leavitt's Diamond, Bostrom and Heinen's (1977) STS framework and Davis et al., (2014), the processes element specifically from Davis et al., (2014) framework and the organisation and its structure from Bostrom and Heinen's (1977) framework. Davis et al., (2014) emphasised culture and goals in his framework, and these were included in the Organisation element as culture of organisation, the People element as culture of people's performance and goals of the organisation for improved inventory accuracy. Collating these selections to inform the development of

Figure 9 further emphasises one of the core Emery & Trist's (1978) STS principles, that these elements must work in joint optimisation for efficient work system performance in this case for accurate inventory data in IMS. Embedding these elements into the selected OPPT, ensures they are simplified and concise, allowing ease of understanding for organisations. The OPPT approach can be used as a holistic lens with which to view an inventory management system to improve operational performance.

2.6 Inventory Management System Challenges and Their Causes

Organisations face numerous challenges affecting their ability to accurately manage inventory, which are explored in the following sections. The section starts by looking at the challenges in inventory management systems, and the challenges of inventory data are then explored in more detail. The causal factors responsible for the inventory management system challenges are categorised using the socio-technical approach of OPPT into Organisation, People, Process and Technology to ensure a holistic view of the challenges faced in IMS.

2.6.1 Inventory Management System Challenges

The following section explores the different inventory management system challenges, including inventory inaccuracy, stock-outs, forecasting errors, lost/misplaced inventory and transaction errors that are symptoms of poor inventory management. The factors causing the inventory management system challenges to occur are also discussed in Section 2.6.2.

2.6.1.1 Inventory Inaccuracy

Inventory inaccuracy refers to the discrepancy between the recorded level of inventory and the physical level of inventory, resulting in inaccurate inventory data (DeHoratius et al., 2008; Wang et al., 2018). Inaccurate inventory levels are a significant problem for both SMEs and large organisations, especially within the retail industry, as it contributes on average to around 10% loss in profits (Uçkun et al., 2008; Tao et al., 2020; Vatumalae, 2022). Three studies showed that at least 65% of stock-keeping unit levels reported by the system, did not corroborate with the physical level of inventory (Fleisch & Tellkamp, 2005; Uçkun et al., 2008; Suriya & Porter, 2012). A further study found that during an investigation of around 500 stores, only 50% of the recorded inventory levels were equivalent to the physical inventory level for sale (Tao et al., 2020). Inventory data quality underpins the other challenges explained in this section.

2.6.1.2 Stock-outs

Inefficiently maintaining inventory levels can result in stock-outs, where sufficient stock is unavailable to fulfil customer orders, negatively impacting sales and customer satisfaction causing backlogs and delays until the next delivery (Goyal, 2016; Muchaendepi et al., 2019; Madeka et al., 2022). A survey study estimated that only 15%- 23% of customers are willing to delay a purchase when they are informed of an out-of-stock item causing a decline in sales (Patil & Divekar, 2014). Avlijas et al., (2015) states the average stock out rate (percentage of inventory items that are not in stock at the time of the audits) is at 7-8% resulting in financial loss of up to 4% of total sales. Although holding insufficient inventory can cause inventory stock-outs, holding excess inventory can tie up the organisation's investments if unsold. Therefore, inventory management is critical to avoid these costs incurred by the organisation (Kasim et al., 2015; Nemtajela & Mbohwa, 2017).

2.6.1.3 Forecasting Errors

Forecasting predicts future sales and the inventory level required for fulfilment. If excessive stock is ordered, there may be insufficient demand for it resulting in storage space being taken up and associated holding costs. However, if insufficient stock is ordered this may result in lost sales (Bagchi, 2014). Forecasting aids in setting appropriate levels for triggering replenishment orders of inventory. The failure to replenish inventory when needed as per the forecasting, results in zero physical inventory available known as ‘Freezing’ (DeHoratius et al., 2008). Poor forecasting triggering inaccurate replenishment is a critical challenge faced by organisations, especially SMEs (Nemtajela & Mbohwa, 2017).

2.6.1.4 Poor Inventory Storage

Poor inventory storage is where inventory is not organised and assigned to designated locations (Fleisch & Tellkamp, 2005). When there is no location assignment for inventory, it can be difficult to be located, hindering the ability to fulfil orders. This also negatively impacts warehouse operations, causing longer picking time for orders and increasing labour costs overall locating items (Pontius, 2017).

2.6.1.5 Lost/ Misplacing Inventory

Misplacing inventory can happen throughout the warehouse, where items are not placed in their designated location and, therefore, are unable to be found. Sarac et al., (2010) state how products not in the correct place and unavailable to sell are classed as inaccessible inventory. If these items are found too late, they can become unsaleable, decreasing sales. This results in lost sales, reduction in profits, increased inventory costs due to reordering, and cost of man hours spent trying to track down the misplaced inventory (Fleisch & Tellkamp, 2005; Singh & Singh, 2014).

2.6.1.6 Transaction Errors

Transaction errors occur in the inaccurate recording of transactions regarding inbound and outbound inventory, including receiving, shipping, auditing, and incorrectly identifying items (Rekik et al., 2015). For example, the quantity of inventory delivered by the supplier can differ from the purchase order, resulting in inbound inventory transaction errors (Sarac et al., 2010).

To summarise, this section explored six core inventory management system challenges:

- Inaccurate inventory data
- Stockouts
- Forecasting Errors
- Poor inventory storage
- Lost/misplaced inventory
- Transaction errors

Analysis of the inventory management system challenges identifies the overarching problem lies in inaccurate inventory data, as all the IMS challenges relate to inventory data. Therefore, the inventory data challenge is that inventory data quality needs to be improved linking back to the research aim. The causal factors relating to inaccurate inventory data are the incorrect recording of transactions or people involved ignoring crucial errors and continuing operations. The causal factors of IMS challenges are further explored in more detail in the following section.

2.6.2 Causal Factors of Inventory Management System Challenges

This section explores the causal factors contributing to inaccurate inventory data in the inventory management system, which causes the IMS challenges discussed in Section 2.6. The factors have been categorised using the socio-technical approach of OPPT into Organisation, People Process, and Technology, as explained in Section 2.5.6.

2.6.2.1 Organisational Factors

This section explores the organisational factors that impact the data in the inventory management system that cause the inventory management system challenges to occur, covering resources and budget, organisational structure and strategy, policies affecting IMS and the lack of staff training.

2.6.2.1.1 Resources and Budget

SMEs have limited resources and do not have the time or budget to, in this case, implement effective inventory management practices and routines (Kumar et al., 2015). This results in inventory management challenges, such as inefficient replenishment and inventory data inaccuracy, due to a lack of processes and policies in place for auditing and limited resource allocation to maintain accurate inventory data (Kumar et al., 2015). There is a substantial difference between SMEs and large organisations, as large organisations have access to the resources and technical budgets to implement new technologies and strategies (Kumar et al., 2015).

2.6.2.1.2 Organisational Structure and Management

SMEs have limited understanding of how IMS should be embedded within organisational structures in practice (Vries, 2005). Zomerdijik & Vries (2003) and Vries (2005, 2020) identify 4 dimensions relating to the organisational structure and context to be crucially considered when implementing an efficient IMS: the allocation of inventory-related tasks, decision-making processes, communication processes and behaviour of the stakeholders (all level employees) involved. Organisations pay little attention to their organisational structure and stakeholder responsibilities when managing inventory operations effectively, so considering these elements is important when dealing with a practical inventory control problem (Zomerdijik & Vries, 2003). For example, poorly defined roles and responsibilities can lead to inaccurate inventory data where staff are unclear who is responsible for updating inventory records and conducting audits. It is important to consider the attitudes and perceptions of the stakeholders involved alongside the organisational structure and processes when implementing an IMS to ensure its effective operation (Vries, 2005). Not considering organisational elements such as, allocation of responsibilities and authorities regarding inventory management, application of cross-functional teams, stakeholders communication and behaviour aspects between departments involved are some examples of the organisational issues (Vries, 2005). This links back to causing inaccurate inventory data due to people's behavioural culture of complacency and ignoring errors as well as the lack of accountability in completing inventory related tasks efficiently (Zomerdijik & Vries, 2003; Rekik et al., 2015).

In addition to these challenges, comes a lack of commitment, poor communication and coordination by higher management and failing to provide the required organisational support to effectively implement best practices in inventory management (Gulama, 2019). Also, higher management can be reluctant to increase resources/budget to invest in modern technologies that can facilitate effective inventory management (Gulama, 2019).

2.6.2.1.3 Policies

When implementing an IMS, some organisations often commit the mistake of not applying clear and well-defined policies to aid in effective inventory management (Vries, 2007). Strack (2010) explains the importance of policies such as, periodic/continuous review, which are vital to maintaining efficient levels of inventory to meet customer demand. Inventory management policies are discussed in Section 2.7.

2.6.2.1.4 Lack of Training

Efficient operation of inventory management systems require staff to be trained to effectively follow the defined processes involved. Gulama (2019) and Kittisak (2023) state that there is a lack of employees who are trained, experienced and competent professionals who understand inventory management processes and the importance of the processes (Singh & Singh, 2014; Ahmad & Zabri, 2018). There are instances where employees can often be neglectful of inventory errors and inefficiently use the IMS in place; for example, errors with accurately recording inventory transactions result in inaccurate inventory data due to the lack of training provided in learning and understanding how the IMS works to avoid human errors (Nemtajela & Mbohwa, 2017; Gulama, 2019; Kittisak, 2023). The lack of skill and understanding of people in how the IMS works results from a lack of training, ultimately leading to data errors within the system as data entry is incorrect and delayed (Xiaoping, 2009). Frazier & McComb (2015) state that SMEs may not have the resources to provide the necessary training to employees as most organisations recruit unqualified staff, resulting in inventory data errors in the IMS.

2.6.2.2 People Factors

The people factors that cause inaccurate inventory data include miscommunication when sharing information (Muchaendepi et al., 2019). Miscommunication is a significant factor contributing to inaccurate inventory data in IMS and, therefore, is one of the most important things to consider to ensure efficient operation (Muchaendepi et al., 2019). It is also common for an organisation's staff to have a culture of complacency, ignoring critical inventory errors and continuing with operational activities, which results in inaccurate inventory data levels (Rekik et al., 2015; Tao et al., 2020). A combination of poor allocation of tasks, poor communication, and poor behaviour impacts the quality of inventory data, resulting in continued discrepancies (Zomerdijik & Vries, 2003; Rekik et al., 2015). Organisational behaviourists stress that communication underlies all aspects of organisational operations, and it is therefore important to consider effective communication in inventory management (Vries, 2005; 2020).

It is important to consider human factors when considering the performance of inventory management systems, to ensure efficient system performance (Winkelhaus & Grosse, 2022). Human involvement can cause issues within the warehouse environment, for example, misplacing a product in the incorrect location can significantly impact the inventory data level accuracy and lead to an unfulfilled customer order (Pramodhini et al., 2023). The movement of inventory in and around a warehouse is usually done by people, leading to human errors such as misplacing inventory, ultimately causing inaccurate inventory data (Rekik et al., 2015; Munyaka & Yadavalli, 2022; Pramodhini et al., 2023). A finding from Munyaka and Yadavalli's (2022) study is that traits of inventory managers, such as personality, knowledge, intelligence, and interests, impact their performance during inventory-related tasks. The findings indicated that the 'intelligence' trait was the sturdiest predictor of inventory routines, whereas limited 'interest' in social matters specifically had led to worse inventory performance, resulting in higher costs. In agreement, Winkelhaus & Grosse (2022) emphasise that humans, whether conducting tasks manually or through using technology, play a significant role within all warehouse and inventory management operations and can significantly impact the quality of inventory data accuracy.

2.6.2.3 Process Factors

The process factors that cause the inaccurate inventory data, include: a lack of standardized processes, lack of integration with other manual and technological processes, and lack of detailed standard operating procedures in place. Alam et al., (2024) found that standard operating procedures can be too general and lack specific detail, thus causing issues when implementing the procedures, resulting in poor IMS performance. Some organisations do not apply new, updated and well-defined processes during implementation of IMS to ensure smooth performance (Vries, 2005; 2007), resulting in the misalignment of the existing processes.

The lack of integration and poor alignment with other existing processes and technological capabilities results in fragmented workflows, data silos and inaccuracies directly impacting inventory data accuracy and operational performance of IMS. Data silos emerge when the inventory management system is not integrated with other processes which prevents cross-functional visibility. This then limits the ability for decision-making regarding inventory levels, and demand planning leading to inventory level inaccuracies and stock-outs (Christopher, 2016). Siloed systems in SMEs, without effective process integration, result in data being unable to flow seamlessly between the IMS and other systems or technologies leading to delays, errors and poor data quality in inventory management (Christopher, 2016). Gunasekaran et al. (2001) state that a lack of integration between IMS and supply chain processes results in delays and transaction errors and misalignment with other processes like procurement and order fulfilment. This can result in errors in updating inventory levels, disrupting order fulfilment schedules and inventory level accuracy. IMS processes are only considered successful if all processes are successfully integrated and all elements of an organisation interact with one another, in this case, the people, processes and technology (Salama et al., 2009).

2.6.2.4 Technology Factors

Organisations face technology challenges in IMS related to the types of automated identification technologies (AIT) used to track inventory. Although technologies such as barcodes or RFID tags have made tracking inventory easier, they are prone to error (Kumar & O'Reilly, 2013). Signal interference or damaged RFID tags and barcodes can cause missed scans. This results in inaccurate inventory levels, which disrupting forecasting and lead to stockouts (Jones & Garza, 2011). Additionally, as barcode readers require the barcode to be in line of sight before scanning, errors such as double scanning or missed scanning of an inventory item can result in inaccurate inventory levels recorded in the system. RFID can also be prone to errors such as poor synchronisation between the data and the system in place leading to discrepancies in inventory data (Schmidt, 2005). Implementation of RFID can still be more expensive, as well as creating mass volume of data making it difficult to manage overall. Another concern is the potential invasion of privacy when using RFID tags, as a study found that consumer groups are worried that the tags would be used to track people instead of goods (Attaran, 2006).

Another technology challenge is adopting technology advancements as not all organisations are able to adapt and transform themselves to work with newer technology (Chanda & Aggarwal, 2014; Kumar et al., 2015). Ineffective technology adoption causes inaccurate inventory data due to the difficulty in communication between IT systems in sync. Systems integration can be complex integration, with high implementation and maintenance costs, which can be a significant barrier for SMEs due to poor technology planning and the potential for security risks (Muchaendepi et al. 2019). Technology adoption can also be hindered by user resistance to technological change, as some staff may lack the knowledge and skills to use new technologies, leading to frequent human errors (Wölbitsch et al. 2021; Zuma & Sibindi, 2024).

Overall, this section has explored the organisational, people, process, and technology causal factors that result in inaccurate inventory data leading to IMS challenges resulting in poor operational performance.

The IMS challenges outlined in section 2.6.1 and their causal factors explained in section 2.6.2, relate to inventory data being at the core of the IMS challenges. This is also supported by Jones & Garza (2011) and Tejesh & Neeraja (2018), who state that accurate inventory data is vital and is the core of IMS working efficiently. The overarching inventory data challenge is that inventory data quality needs to be improved. Within the literature of information systems, Wang & Strong (1996) explain that data quality and user satisfaction are major dimensions to evaluate an information system's success and within these two dimensions are attributes such as accuracy, timeliness, reliability, precision, completeness and relevancy.

The following section outlines data quality, its attributes, frameworks and measures, leading to selected data quality measures to be used in this research to improve inventory data quality.

2.7 Data Quality

Research regarding data quality started as early as the 1950s, when researchers began to study issues arising in the quality of data (Wang & Strong, 1996). As technology rapidly developed, data quality issues increased, being brought to the attention of the Total Data Quality Management group of MIT, led by Professor Richard Y. Wang, in 1996. Data quality is the measurement of the agreement between the data presented by an information system and the same data in the real-world (Heinrich et al., 2018). Azeroual et al., (2018) define data quality as a *"multi-dimensional measure of the suitability of data to fulfil the purpose bound in its acquisition".* Wang & Strong (1996) define data quality as a set of data quality attributes that represent a construct of data quality. Data quality comprises of different data quality attributes such as accuracy, completeness, timeliness and consistency (Ehrlinger & Wob, 2022; Heinrich et al.,2018). Although there are a large number of publications, concepts and theories regarding data quality, it still lacks clarity on how to map concepts from theory, i.e. mapping the attributes to a practical implementation (Ehrlinger & Wob, 2022).

2.7.1 Importance of Data Quality in IMS

In e-commerce retail, consumers depend on the retailer to have accurate inventory data to place an order and use this data to make accurate decisions regarding purchasing (Raman, 2000). The inaccuracy of inventory data causes social impacts and financial loss if not identified and corrected in a timely manner, emphasising the importance of measuring data quality (Raman, 2000). For example, periodic physical audit data can be used to measure inventory data accuracy. Accuracy is one of the most cited data quality attributes found amongst the literature studies presented in Section 2.7.3. Several definitions of data accuracy in literature have been outlined in Table 4.

Table 4 Data Accuracy Definitions

Author	*Definition of Accuracy*
Ehrlinger & Wob (2022)	Defines accuracy as the closeness between an information system and the real world being modelled
Tee et al., (2005)	Define accuracy as the correspondence of recorded values to the actual values of the associated real-world object.
Wang & Strong (1996)	Defines accuracy as the extent to which data is correct, reliable and certified.
Wang et al., (1995)	Define accuracy as when the recorded value matches the actual value.

The author's definitions of accuracy in Table 4 all refer to the correspondence between the recorded data values and the actual physical data values; however, Wang & Strong (1996) explain beyond this, stating that accuracy also includes other characteristics impacting the reliability and certification of the data. Inaccurate data leads to poor data quality which can cause operational inefficiencies, poor decision making and disruptions within a managed system, detrimental to the organisation overall (Tee et al., 2005; Madnick et al., 2009; Makhoul, 2022). Research within e-commerce shows that organisations are unaware of the concerns about poor data quality; in instances of awareness, very few will actively engage in improving data quality and reducing the issues (Tee et al., 2005; Vijayan Nambiar & Prasad Nair, 2017). Ehrlinger & Wob (2022) state that poor data quality costs an average of $15 million per year in losses.

Data quality issues and their causes can vary from technical (poor integration of data from disparate sources) to non-technical (lack of an interrelated organisational strategy, ensuring all stakeholders have complete data in a timely manner) (Madnick et al., 2009). The next section further discusses measuring and assessing data quality.

2.7.2 Data Quality Assessment

Data quality assessment has become critical for operational success (Ehrlinger & Wob, 2022). To conduct data quality assessment, measures are required. The international organisation of standardisation outlines that measures are classified according to the different attributes of data quality such as accuracy, timeliness in terms of what is being measured (Mocnik et al, 2018). A data quality metric is objective and measurable, providing quantifiable values, which are important for evaluating the quality of data (Azeroual et al., 2018). Ehrlinger & Wob (2022) explain that the term assessment is often used as a synonym for measurement, however the definitions are different. Measure describes ascertaining the size or amount of something, using an instrument or device, whilst assessment is evaluating the ability or quality of something. This extends the measurement concept by evaluating measurement results and drawing a conclusion regarding the assessment (Ehrlinger & Wob, 2022). If a dataset is assessed for its quality by a certain measure, this is named intrinsic and if it does not require any further data other than the dataset, it is named extrinsic (Mocnik et al., 2018).

For data quality assessment, Wang & Strong, (1996) state the attributes for measure are derived from data deficiencies, which are the inconsistencies between the real world system and the information system. Using this approach the researcher is free to select the attributes most relevant to the study. The assessment of data quality is an on-going effort that requires awareness of the fundamental data quality metrics instead of a one size fits all set of metrics (Pipino et al., 2002).

Data quality improvement requires looking into interactions of data quality with processes, strategies and policies, therefore resulting in changes in processes, strategies and organisational behaviour to improve data quality (Madnick et al., 2009). Chen et al., (2014) state that the interview method is useful to help identify the root causes of poor data quality and then design efficient strategies to improve data quality. In addition to the interview method, field observation and validation are also useful when assessing data quality as showing the reference of data in the real world will give users confidence in the data quality.

2.7.3 Data Quality Attributes

Data quality attribute is a term used to characterise a feature of data that can be measured or assessed within defined standards to understand the data quality (Vijayan Nambiar & Prasad Nair, 2017; Mocnik et al., 2018). Data quality attributes are sometimes referred to as dimensions, some of which are: accuracy, timeliness, precision, reliability, relevancy and completeness (Wang et al., 1995; Tee et al., 2005). The list also includes validation, availability, reliability, consistency and credibility (Wang et al., 1995; Tee et al., 2005). Several attributes of data quality are presented within the literature such as, Chen et al., (2014) study presents 49 attributes, and Wang & Strong (1996) study presents 179 attributes showing the vast amount of data quality attributes identified. The attributes are embedded in the data quality frameworks discussed in the following section.

Table 5 shows the combined list of data quality attributes across the various literature and frameworks that have been analysed regarding data quality by Pipino et al., (2002), Wang & Strong (1996), Chen et al., (2014), Dedeke (2000) and Cai & Zhu (2015) in Section 2.7.3.

Table 5 Data Quality Measures Collection from Frameworks Analysed from Literature

Attributes		
Accuracy	Free-of-error	Precision
Timeliness	Concise	Ease-of use
Reliability	Clarity	Helpfulness
Traceability	Correctness	Verifiability
Completeness	Convenience	Coherence
Relevancy	Speed	Target group orientation
Value-added	Accessibility	Validity
Availability	Robustness	Consistency
Ease-of understanding	Security	Usability
Cost-effectiveness	Efficiency	Flexibility
Importance	Preciseness	Synchronisation
Logically connected	Uniqueness	Well-presented
Integration	Verifiability	Robustness
Critical	Integrity	Confidentiality
Responsiveness	Appropriate data	Structure

2.7.4 Existing Data Quality Frameworks

A data quality framework is a set of guidelines and techniques that defines a process to assess and improve the data quality (Batini et al., 2009). Data quality assessment methodologies and frameworks help organisations understand data quality attributes, assist in developing processes to measure data quality and investigate its relationship to organisational processes (Tee et al., 2005). Several data quality methodologies also referred to as frameworks have been proposed. For example, the TQM (Total Data Quality Management) proposed by Wang (1998), the AIMQ (A Methodology for Information Quality Assessment) proposed by Lee et al., (2002) and the Data Quality assessment methods proposed by Pipino et al., (2002).

2.7.4.1 Wang & Strong (1996) A Conceptual Framework for Data Quality

Wang & Strong (1996) explain that to improve data quality, it is important to understand what data quality means in a specific context. Wang & Strong (1996) present a conceptual framework that captures the key attributes of data quality that are important to data consumers in order to measure and improve the data quality. The 179 attributes identified were organised into 15 attributes and then clustered into 4 main categories of data quality: intrinsic, contextual, representational and accessibility presented in Table 6. These 4 categories emphasise Wang & Strong's (1996) findings that high-quality data should be intrinsically good, contextually appropriate for the task, clearly represented and accessible to the data consumer. The study found that information system managers were able to better meet their data consumers' data quality needs with these attributes as they are all collected from data consumers instead of being theoretically defined. Wang & Strong (1996) explain that the framework is methodologically sound and is useful for measuring, analysing and improving data quality.

Table 6 Breakdown of Data Quality Dimensions (Sourced from: Wang & Strong (1996)

Categories of Data Quality	**Description**
Intrinsic	Can be assessed independently (accuracy, believability, objectivity, reputation).
Contextual	Attributes must be considered within context of task (value-added, relevancy, timeliness, completeness, appropriate amount of data).

Representational	Aspects related to the format and understandability of data (representational consistency, concise representation, interpretability, ease of understanding).
Accessibility	Degree to which data is accessible but secure (accessibility, access security)

2.7.4.2 Cai & Zhu (2015) Universal, Two-layer Data Quality Framework

Cai & Zhu (2015) present a framework where the main attributes of data quality are, availability, usability, reliability, relevance and presentation quality as shown in Figure 10. These are divided further into sub elements. Availability includes accessibility, timeliness and authorisation, which determine the convenience of data access. Usability includes definition, credibility and metadata, which show a level of acceptance. Reliability includes accuracy, integrity, consistency, completeness and auditability which refer to the users trust on the data. Relevance refers to how effective for purpose the data is, and presentation quality includes readability and structure relating to satisfaction of the user. The framework outlines these data quality attributes in a well-structured manner showing a two-level hierarchy (Cai & Zhu, 2015). This framework aims to address the challenges that arise in big data due to significant technological advancements continuously increasing the amount of data. These challenges are discussed in the study as: the diversity of data sources brings abundant data types and complex data structures, data volume is high and difficult to judge data quality in a reasonable time, data changes fast and timeliness of data is short and finally that there are no approved data quality standards for big data as the research has just begun. Cai & Zhu (2015) explain the importance of the use and analysis of big data being based on accurate and high-quality data to generate value from it, therefore a two-level hierarchy framework was developed, identifying key attributes for measuring data quality of big data.

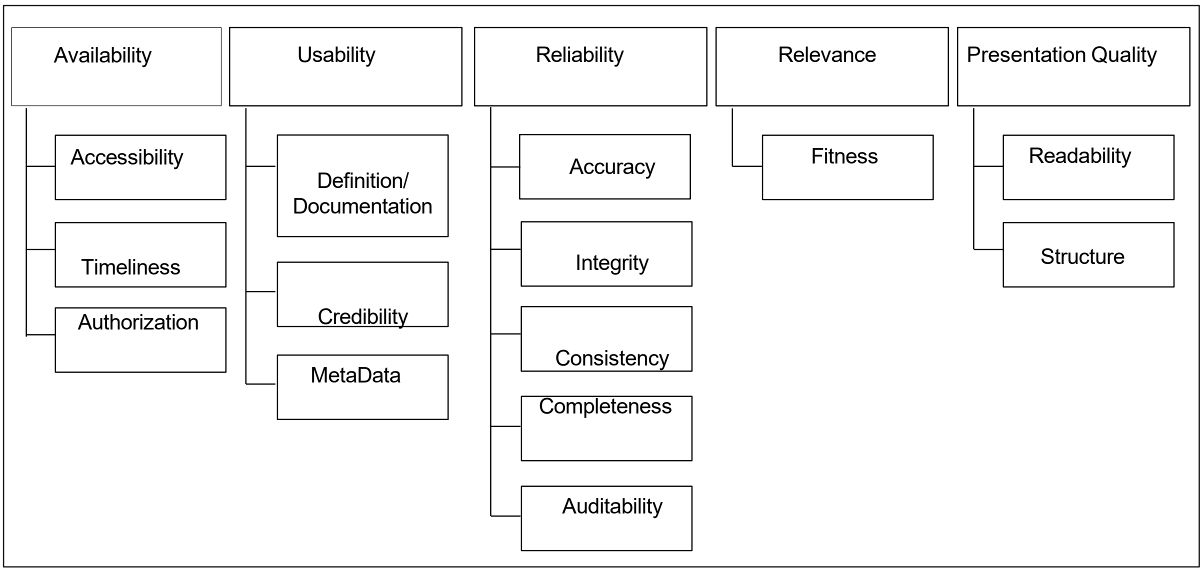

Figure 10 A Universal Two-Layer Data Quality Framework for Assessment (Sourced from Cai & Zhu, 2015)

2.7.4.3 Dedeke (2000) A Hierarchical Framework for Information system Quality

Dedeke (2000) presents a framework developing the data quality attributes specifically for information systems (IS), firstly identifying the components of IS being data, interface, work/task design and soft/hardware system, presented in Figure 11. The data quality attributes are then derived from the relationship between these IS components. The data quality attributes are categorised under 5 main attributes of IS quality: ergonomic quality, accessibility quality, transactional quality, contextual quality and representation quality. Three of these categories: representation, contextual and accessibility quality have been covered in Wang & Strong (1996) framework showing crossover as that framework is also developed similarly for information systems domain. Ergonomic quality defines the degree to which the soft/hardware system interface is designed to meet user needs. Transaction quality evaluates the programming of a specific work process (logic) with the software. The premise of the framework states that the quality of an IS cannot be considered in isolation from data quality, including the attributes and processes involved in data utilisation.

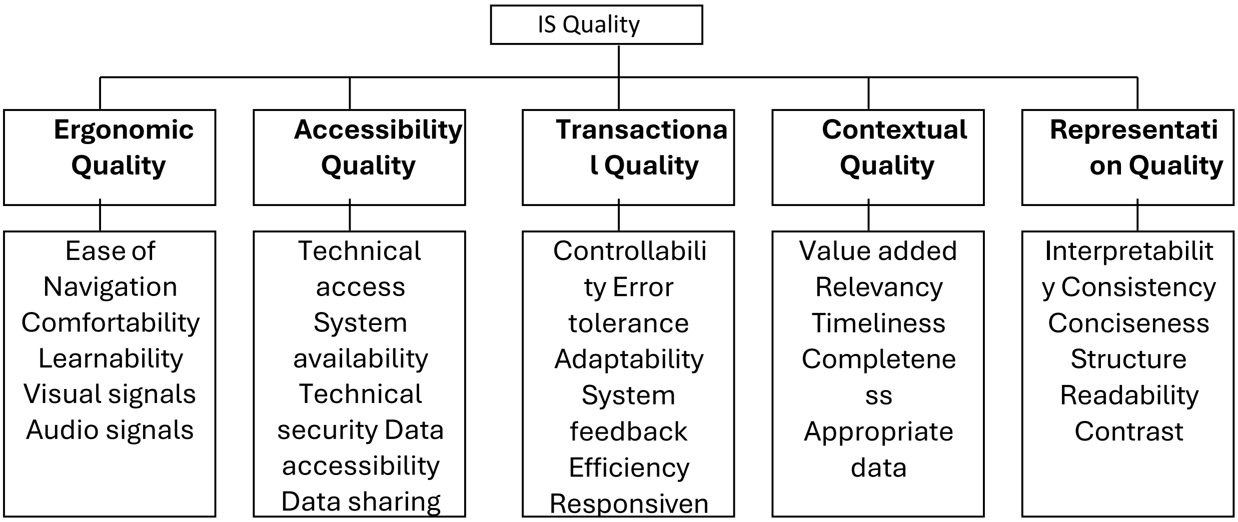

Figure 11 Hierarchical Framework for Information system Quality (Sourced from: Dedeke (2000)

The data quality frameworks presented identify a range of data quality attributes specific to information systems (Wang & Strong, 1996; Dedeke, 2000), and big data (Cai & Zhu, 2015). The following section builds on this work to define data quality attributes explicitly selected for inventory management systems.

2.7.5 Selected Data Quality Attributes for Measure

As Wang & Strong (1996) state, attributes for measure are derived from data deficiencies, this research adopts this same strategy when selecting data quality measures to improve inventory data quality in IMS. This strategy allows the researcher to select the data quality attributes for measure which are most relevant to the study. In this case, inventory data is at the core of the IMS challenges and their causal factors, as explained in Section 2.6.2. Table 7 presents data quality attributes and definitions that are relevant to improving inventory data quality. These have been derived from the IMS challenges and the causal factors discussed in Section 2.6.

Table 7 Selected Data Quality Attributes relevant to this study

Selected Attributes	**Definitions**	**Justification**
Accuracy	How correct and error-free the data is	The inventory data recorded in the IMS needs to directly match with the physical inventory level to ensure orders can be fulfilled and to appropriately inform decisions about recording inventory.
Timeliness	How up-to-date and available the data is when needed	Timely updates ensure that inventory data reflects the current state, enabling decision-making and responsiveness to

		demand. This fosters confidence among staff who rely on up-to-date data to execute tasks effectively.
Reliability	The consistency of data over time and its ability to be depended on	Reliable data minimises system errors and disruptions, ensuring continuous and consistent operation. Staff can rely on the data, reducing frustration and improving productivity.
Traceability	The ability to track the origin and history of data	Traceable inventory data allows organisations to track the movement and history of items. Traceability enables staff to identify root causes of issues, enhancing transparency and accountability of issues.
Completeness	The degree to which all necessary data is captured	Complete data ensures that all necessary attributes of inventory data, such as quantity, state, location, are available in full to aid in activities such as decision-making, forecasting and storing inventory.
Relevancy	The relevance of data to the purpose of the data being evaluated	Relevant data ensures that only information related to and pertinent to inventory tasks is provided, reducing data overload.
Value-added	How well the data contributes to achieving organisational objectives and enhances decision making	Data should contribute to achieving organisational objectives within an inventory management system, such as reducing costs and improving inventory management-related tasks such as the accuracy of inventory and reducing discrepancies in inventory auditing.
Ease-of understanding	How easily stakeholders can interpret the data	Simplified data representation, is easier to understand, ensures that staff with varying technical skills can interpret and act on the inventory data given. From a technology perspective, this would support clear interface design to comprehend system data and also allow staff, both technical and non-technical, to engage with and communicate inventory data amongst each other.
Integration	The ability to combine the data from various sources for a unified view	Integrated data allows for seamless communication between the inventory management system and other systems/technologies, ensuring data is kept up to date and accurate, as well as improving operational efficiency. This also enhances collaboration across departments when managing inventory.
Clarity	The clearness of data presentation	Clear data presentation minimises ambiguity and prevents misinterpretation of inventory data. This reduces errors and

		enhances staff confidence in outputs achieved through the inventory management system.
Efficiency	The speed and resource efficiency with which data can be collected and analysed	Efficient data refers to minimal resource consumption used to gather and use the data to complete inventory data related tasks, reducing resource costs.
Ease-of use	How simple and user friendly the data is to access, understand and interact with	Ease of use refers to how simple and intuitive the data is for users, in accessing and understanding the data to ensure effective interaction. It reduces errors in processing inventory data.
Validity	The extent to which data aligns with what it is supposed to measure	Valid data adheres to rules and constraints as it ensures its appropriateness for the inventory task. This also enhances data integrity and reduces chances of staff encountering incorrect or inaccurate data.
Consistency	The uniformity of data over time and across various datasets	Consistency refers to the uniformity and agreement of data and ensures that data remains aligned and logically coherent to support decision-making. This ensures operational efficiency as it reduces time spent in reconciling any inconsistencies in data.
Usability	How easily the data can be utilised for decision-making	Usable data emphasises the simplicity and practicality of the data to ensure it can be utilised by its users. This can come in the form of system data that is in the correct format and, therefore, is recognised and used for processing or written data that is comprehensible and, therefore, can be used in reporting or decision-making.

The selected data quality attributes for inventory management systems align with addressing the IMS challenges as outlined in Section 2.6 and this is presented in Table 8.

Table 8 Mapping the Data Quality Attributes to IMS Challenges

IMS Challenges	**Data Quality Attributes**														
	Accuracy	Completeness	Timeliness	Consistency	Ease of understanding	Clarity	Ease of use	Usability	Relevancy	Value added	Validity	Traceability	Integration	Efficiency	Reliability
Inventory Inaccuracy	●	●		●							●	●			
Stock-Outs		●	●						●	●				●	
Forecasting Errors	●		●						●		●		●		
Poor Inventory Storage					●	●		●				●		●	
Lost/ Misplaced Inventory				●			●					●	●		●
Transaction Errors	●			●			●				●				●

The following section outlines critical success factors to improve inventory data quality and achieve best practice in inventory management.

2.8 Critical Success Factors of Inventory Management Systems

Critical success factors (CSF) for achieving best practice in inventory management, lead to efficient operation of inventory management systems (Rawat & Anusandhanika, 2015). As e-commerce businesses navigate inventory management and its complexities, it is imperative to adopt best practices (Groenewald & Kilag, 2024). CSF aids organisations in identifying key areas of concern to provide successful measures to target improvement (Grabski et al., 2011). CSF for IMS can either be technology-driven or non-technology-driven. Non-technology CSFs include the policies and processes, whereas technology-driven CSFs utilise technologies such as AIT (Fleisch & Tellkamp, 2005). Policies cover a range of areas, such as storage location assignment policy, replenishment policy, process integration, cycle count practice, Just In Time (JIT) and Economic Order Quantity (EOQ).

2.8.1 Design and Plan an IMS Effectively

Effective planning and designing of inventory management systems requires a systematic approach that considers the organisational needs, architecture, stakeholder interests, attitudes, technological scope, processes and procedures, ensuring that all elements of the IMS can work together successfully (Vries, 2005; 2013). Understanding and working around the system design and architecture that supports scalability and flexibility as well as selecting appropriate technologies to integrate with the IMS, is crucial for operational coherence and inventory management accuracy (Soni et al. 2024). Otobo & Alegbe (2024) state that when designing and planning an IMS, it is important to understand the organisational requirements, such as inventory types, volume, existing processes and workflows, for enhanced operational efficiency. Shaza and Hiba (2024) explain, when planning and designing the IMS, training material must also be developed to support and manage the transition to the IMS so that it is successfully adopted and implemented. This results in efficient operation and increased inventory data accuracy.

2.8.2 Implement IMS Policies

The inventory management system policies consist of, periodic or continuous review, replenishment, Just In Time (JIT), Economic Order Quantity (EOQ), Quick Response (QR), storage assignment and stock keeping unit assignment which are explained in this section.

2.8.2.1 Periodic or Continuous Review Policy

Periodic and continuous review policies help to efficiently monitor inventory for replenishment (Strack, 2010). The periodic review implies that the stock level will be checked after a fixed period, and an ordering decision will be made. If the inventory quantity is below a certain level, an order is then processed for a variable quantity of stock to be delivered (Razi, 2003). The continuous review policy underlines that the stock level will be monitored continuously, resulting in a fixed quantity of stock being ordered when the stock falls below the threshold, initiating a re-ordering decision to be made. These basic policies can be adapted depending on the organisation's processes to ensure efficient inventory management (Strack, 2010).

2.8.2.2 Replenishment Policy

Replenishment policies are important in inventory management as they assist in determining the frequency of inventory orders to meet customer demand and maximise customer satisfaction by lowering the number of back orders and delays (Sarac et al., 2010). Efficient replenishment of inventory ensures the sufficient availability of stock to avoid delays in fulfilment (Sarac et al., 2010; Amirrudin et al., 2023). This is critical for warehouses with fast-moving items such as e-commerce warehouses or retail distribution centres. There are two types of replenishment policies where either the organisation chooses to initiate replenishment in-house using the re-order point and order quantity controls, or allow suppliers to replenish inventory using the Maximum Level (ML) and the Order-Up-To-Level (OU) controls.

The first type of policy is where the organisation is in control of replenishment and uses the two controls: re-order point and order quantity. Cobb et al., (2015) explain that a re-order point determines when stock needs to be ordered and an order quantity determines the re-order quantity. Amirrudin et al., (2023) explain that a re-order point is also known as necessary storage, an inventory level for a product that, when reached, triggers the re-ordering of more inventory. Having a re-order point is one of the most effective methods to improve replenishment in inventory management, ensuring availability for customer demand. The re-order point is determined by the minimum level, re-order quantity, consumption rate and lead time to receive new inventory shipments (Amirrudin et al., 2023).

The second type of policy is where the suppliers are in control of replenishment and uses two controls: ML and OU. The ML control allows the supplier to freely deliver any quantity to a retailer whilst knowing the retailer's inventory capacity. The OU control allows the supplier to know the inventory capacity of the retailer and deliver only the required quantity (De Vos & Raa, 2018). Overall, replenishment policies rely on accurate inventory data and aid organisations in avoiding stock-outs where insufficient stock is available for orders.

2.8.2.3 Just In Time (JIT)

Just In Time (JIT) is supplying goods in small quantities at frequent intervals at the right place when needed, minimising inventory levels (Barlow, 2002). John et al. (2015) further explain how adopting the JIT technique ensures stock handling costs are minimised and ensures customer demand is met with little waste. This policy significantly reduces inventory storage load. For JIT to be implemented successfully, there must be a high standard of communication and cooperation between the supplier and the retailer/manufacturer (Sheakh, 2018). Organisations implementing JIT reduce excessive inventories and optimise their inventory storage (Sadhwani & Sarhan, 1987).

2.8.2.4 Economic Order Quantity (EOQ)

The Economic Order Quantity (EOQ) model founded by Harris (1990) provides a mathematical formula for calculating the optimal quantity of inventory needed for each stock- keeping unit, balancing and minimising the overall cost of ordering and cost of holding inventory (Panigrahi et al., 2024; Muchaendepi et al., 2019).

2.8.2.5 Quick Response (QR)

Quick Response (QR) enhances supply chain responsiveness by reducing lead times and aligning inventory closely with customer demand, thus minimising inventory levels whilst maintaining sufficient inventory quantity to meet customer demand (Caro et al., 2010). Choi & Sethi (2010) state that QR enables organisations to respond effectively to market trends.

2.8.2.6 Storage Assignment Policy

Storage assignment efficiently manages inventory storage and locations that have been assigned to inventory, based on product type, quantity, size and market demand (Alam et al. 2024). Managing storage space and assigning locations is vital for inventory management, as it aids in maintaining accurate inventory data, preventing misplacement of inventory and minimising stock-outs. This makes it easier to monitor inventory levels and identify when stock is running low (Alam et al., 2024). Staff can then become familiar with these storage locations, reducing the misplacement of inventory (Zhang, 2017). The structure and layout of a warehouse impact the storage of inventory. Decisions relating to space utilisation and locations of certain inventories, can contribute to improved productivity in warehousing operations such as order fulfilment (Zhang, 2017; Jinxiang, 2007).

Storage policies are split into three groups: dedicated storage, randomised storage and class-based storage. The dedicated-based storage policy aims to reduce the travel times for picking inventory by storing high-demand products at dedicated fixed locations (Berg & Zijm, 1999; Gagliardi, 2007). Randomised storage is when items are stocked randomly in various locations according to the available storage space (Berg & Zijm, 1999). Class-based storage is where products are allocated to specific zones or areas in the warehouse (Berg & Zijm, 1999; Gagliardi, 2007).

Randomised storage is referred to as a dynamic slotting technique named chaotic storage (Van Geest et al., 2021; Boysen et al., 2019). This is applied by large online retailers such as Amazon, where they store products in any empty storage bin. It works by breaking down stock-keeping units (SKU) into single units when delivered and allocating them equally throughout the warehouse shelves so that the average distances from anywhere in the warehouse towards the closest unit of each SKU are reduced. Amazon warehouse systems keep track of all the product locations, by scanning the product's barcode and the location's barcode when storing products in the warehouse (Van Geest et al., 2021; Boysen et al., 2019). This enables the picking technology implemented by Amazon, automated guided vehicle (AGV), to be directed to the product using the optimised picking route based on inventory locations.

Rajasekar & Sengupta (2020) propose three principles for implementing the policy of assigning storage locations: housekeeping, identification and training. Housekeeping involves the sorting of inventory to keep the same SKUS together so that inventory can be found quicker by its combined location. Identification requires inventory items to be pre-counted, inspected and stored in sealed containers to identify them for inventory counting/shipping purposes, maintaining the inventory level accuracy. Finally, training ensures that all personnel dealing with inventory are familiar with processes and are correctly trained in effective handling.

2.8.2.7 Stock Keeping Unit (SKU) Assignment

Assigning stock-keeping units (SKUs) provides a unique identifier for each inventory item, enabling precise tracking and recording within the system and during physical checks (Khabbazi et al., 2013). The unique identification code comprises alphanumeric characters and can be used internally in the organisation or for external purposes (Khabbazi et al., 2013). Products for sale are generally stocked in variations labelled with a stock-keeping unit indicating unique variations between the size, colour and style of a product (Yoon, 2015).

2.8.3 Process Integration

Integrated processes are important when implementing the IMS, ensuring it is correctly aligned with the existing organisational and technological processes, other systems and policies. This is important to ensure the flow of accurate data between systems avoiding data silos and fragmented workflows (Christopher, 2016). Some processes may not be compatible with an automated IMS; therefore, organisations may be required to re-engineer their current processes in order for the IMS to work effectively and improve efficiency (Ram et al., 2013; Mohamed et al., 2016; Aqlan & Al-Fandi, 2018). The three main aims for business process re-engineering are, making the processes effective, efficient and adaptable to meet demands (Bhatt, 2000). Performance can be measured by assessing the effectiveness of how several processes are followed by an organisation, in this case, integrated processes within the IMS (Kumar et al., 2015). This helps to ensure that process challenges explained in Section 2.6.2.3, during the implementation of IMS are avoided where processes are not well defined and are not integrated within the organisational structure and existing processes (Vries, 2013).

2.8.4 Standard Operating Procedures (SOP)

A standard operating procedure (SOP) is a detailed description of a process to ensure that the employees execute the process correctly (Stanger et al., 2012). It acts as a guideline to understand each step in the process so that they can be carried out efficiently and consistently (Hadiyanti & Latief, 2018; Nofia, 2023). There are two main objectives of SOPs. First, SOPs can be used to monitor employee performance. Second, SOPs help maintain consistent performance as all personnel follow the same process for inventory handling, thus reducing scope for errors (Alam et al., 2024). This also helps employees understand the role and function of work tasks, clarifying responsibilities and duties, which can minimise administrative errors, duplications and inefficiency (Hadiyanti & Latief, 2018). Examples of SOPs within inventory management are for: inspecting, counting, receiving, storing, shipping and handling (Hadiyanti & Latief, 2018). Implementing SOPs leads to improved inventory data accuracy, a reduction in inventory data discrepancies and overall enhanced operational efficiency in an IMS (Alam et al., 2024).

2.8.5 Inventory Audits: Regular Cycle Count Practice

Regular auditing involves counting of inventories to compare the physical inventory level against the system recorded inventory level. Conducting regular audits in timely cycle counts, reduces discrepancies and improves inventory data accuracy (Vatumalae 2022; Fleisch & Tellkamp, 2005). This also involves cross-referencing an organisation's financial and inventory records to ensure alignment and address any discrepancies for transparency in inventory holdings with monetary value of assets (Esmail Mohamed, 2024). Vatumalae, (2022) recommends that either 4 quarterly or 12 monthly counts be completed throughout a year, as the higher frequency of cycle counts increases inventory data accuracy. Sarac et al., (2010) emphasise that frequently conducting physical inventory counts is the most efficiently used method to align physical and system-recorded inventory levels. Inventory audits are crucial for maintaining accurate inventory data levels and ensuring the availability of inventory to fulfil customer demand (Esmail Mohamed, 2024).

2.8.6 Inventory Inspection/ Quality Check (QC)

Damaged inventory results in inaccurate inventory levels impacting order fulfilment, as if this is undetected, the inventory is incorrectly shown as available for sale (Van Geest et al., 2021). Inspecting and conducting quality checks (QC) of inventory on arrival ensures both quality and quantity are confirmed to process items in saleable condition. This ensures that the IMS accurately records the inventory quantity received that is sellable (Van Geest et al., 2021; Trajanova & Dimitrova, 2023).

2.8.7 Staff Training

Due to the dynamic, evolving nature of inventory management, it is important to have a trained workforce of skilled professionals competent in navigating the IMS and conducting inventory management practices efficiently (Groenewald & Kilag, 2024). Training staff is critical for high operational efficiency and accurate inventory data in IMS. This aims to ensure staff have sufficient knowledge and skills to understand the workings of an IMS, follow effective inventory management processes, and adapt to and use technology correctly (Muturi, 2016; Salih et al., 2023; Ahmad & Zabri, 2018; Groenewald & Kilag, 2024). In addition, Singh & Singh (2014) state that staff should also be educated on the impact of poor inventory management and their task performance should be regularly assessed, to help attain high efficiency in inventory processes. This can be done via monitoring and measuring individual performance.

2.9 Technologies Used in Inventory Management Systems.

As discussed in the previous section, CSFs rely on accurate inventory data; therefore, the ability to capture data quickly and precisely is important to reduce the causes of data inaccuracy, such as manual data entry errors and delays with updating inventory records. Technology can be used to alleviate these causes. Within the inventory management field, information technology is a tool used for monitoring and managing inventory, minimising errors and ensuring accurate inventory records are maintained (Amirrudin et al., 2023). Automated identification technology (AIT) combines physical objects with the virtual digital world (Schmidt, 2005). There are many AITs, such as barcoding, real-time location systems such as, RFID and sensor technologies, which allow the communication of data, ensuring real-time accurate inventory records (Schmidt, 2005). AIT can improve the efficiency of the IMS with automation, minimising manual errors, reducing shrinkage, and minimising stock-outs (Schmidt, 2005). In addition to barcode and RFID, several other technologies can also be adopted as explained by Van Geest et al., (2021) such as, Internet of Things (IoT), robotics, artificial intelligence and augmented reality, which are discussed in the following subsections.

2.9.1 Radio Frequency Identification (RFID)

RFID provides real-time traceability of inventory items. Knowing the exact location of inventory improves processing times of inventory-related tasks such as, inventory counting and reduces the labour costs spent in locating items and their movements for order fulfilment (Suriya & Porter, 2012; Rekik et al., 2015). Sarac et al. (2010) and Mashayekhy et al., (2022) suggest that in facilitating inventory management using real-time data, RFID technologies can reduce inventory loss, increase efficiency and speed of processes, and improve inventory accuracy. In addition, this automated technology helps to minimise manual stock checking (Chai et al., 2023). RFID technology has emerged as a reliable solution for enhancing the reliability of operational IMS processes such as tracking, shipping, and counting, reduces inventory inaccuracies by 20-30% (Suriya & Porter, 2012; Rekik et al, 2015; Lee et al., 2008; Wang et al, 2018; Mashayekhy et al., 2022). Alyahya et al., (2016) and Thiesse & Buckel, (2015) explain that integrating RFID within current systems supersedes manual inventory management by automatically detecting goods in locations and improving inventory handling efficiency. For example, Walmart has estimated cost savings in terms of inventory and warehousing within their RFID-enabled stores of $300 million in improved traceability within warehouses and $180 million in reducing inventory costs (Lai et al., 2005). Using RFID, shrinkage can be reduced from 18% to 11% and stock-outs from 14%-9% and lead times by up to 5% (Attaran, 2006).

2.9.1.1 Implementation of RFID

RFID uses active and passive technology to manage and record the movement of inventory in warehouses. RFID works with three components: the reader, the antenna and the tag. It works when an item or object is addressed with a tag containing a chip which stores the product information and location. Once the antenna emits a signal in range of the RFID reader this is responded to by the tag with a unique code. Once this communication is established, the reader reads and decodes the information received and sends it across to the central system for further processing (Jones & Garza,2011). There are three types of RFID tag, active, passive and semi-passive. The active tags are battery-powered and have a long-read range as well as high memory. Passive tags are not battery-powered and are less costly than active tags; however, the read ranges are considerably lower. Finally, semi-passive tags are similar to active tags where they have a longer read range but are more costly than passive tags (Jones & Garza,2011).

2.9.2 Barcoding Technology:

Barcoding technology is one of the most widely used technologies in organisations to collect data accurately (Attaran, 2006; Mathou & Vlachopoulou, 2001). The barcode strip comprises narrow side-stacked lines of different sizes, storing around 20-30 characters of unique information. Within this character range, the Universal Product Code (UPC) is assigned for the individual item, which then communicates with the computer system to respond when scanned. Two types of barcodes are either Universal Product Code (UPC) for US products or European article number (EAN) for European products. The organisation can also apply their own product codes if it has internal inventory control processes (Mathou & Vlachopoulou, 2001). Barcoding is important in inventory control as it ensures simplicity in managing inventories, allowing accurate data capturing through the scanning of inventory (Attaran, 2006). The beneficial impacts of the barcoding technology are accurate real-time data, improved order fulfilment efficiency and automatic updates of inventory levels within the IMS when integrated (Mathou & Vlachopoulou, 2001).

In addition to barcoding, QR codes are a similar concept based on a two-dimensional code (Ali et al., 2023). This is another type of code that can be scanned and holds an adequate amount of product information. QR codes can be scanned from both phones and scanners with internet access, and by scanning the code, the user can receive the stored information in real time (Ali et al., 2023).

2.9.2.1 Implementation of Barcoding

Hong-ying (2009) explains within inventory management, barcode technology is operated where an individual/unique barcode is linked to a product and its information is stored. When this barcode is scanned, product information can be shown, which improves the efficiency of managing and tracking inventory and reduces the error rate, improving operations (Hong-ying, 2009).

RFID and barcoding technology are popular solutions proposed to reduce inaccuracies in inventory and improve overall inventory management (Kamaludin, 2010). These technologies ensure inventory data is maintained and updated accurately in the IMS. Tracking inventory reduces the risk of inventory being misplaced (Kamaludin, 2010). Alyahya et al., (2016) and Zhu et al., (2012) state that it is vital for businesses to look into efficient technologies for managing inventory as AIT helps to target major errors within inventory management such as stock-outs, shrinkage, lost/misplaced stock and overall improve inventory data accuracy.

2.9.3 Robotics

Autonomous robots, as explained by Winkelhaus & Grosse (2022), are "industrial robots that use a decentralised decision-making process for collision-free navigation to provide a platform for material handling within a bounded area". Using robotics within warehouses to manage inventories can also improve accuracy and efficiency (Singh & Adhikari, 2023). Different robots can perform a range of tasks within the warehouse, such as moving shelves, sorting, handling and palletizing inventory. For example, Dey and Seok (2024) outline an intelligent inventory robot that conducts automated inspection to detect faulty products, helping to control shortages and inaccurate inventory levels.

Some of the leading e-commerce companies, such as Amazon and Alibaba, perform around 70% of their operations using robotics technology (Van Geest et al., 2021). Automation technology, such as robots, can substitute human operators for routine, repetitive tasks such as moving, storing and retrieving goods efficiently within the warehouse, improving consistency and reducing human error (Winkelhaus & Grosse, 2022; Vaka, 2024). This reduces reliance on manual labour leading to labour cost savings and enabling continuous operations as they operate around the clock, reducing delays (Vaka, 2024).

2.9.3.1 Automated Guided Vehicles (AGV)

Forklifts are frequently used to transport inventory within the warehouse; however, they are human-operated, making them time-consuming and resource-intensive. Automated guided vehicles (AGV) are a form of technology used to aid in moving products to their designated storage locations and conduct inventory picking and shipping processes. The AGV navigates through the warehouse along a magnetic tape, integrated grid or even on a pre-programmed route and uses cameras and sensors so that it is aware of its surroundings, enabling safety within the warehouse and minimising the need for human involvement. This allows for efficient and quick organising of inventory, limiting human involvement and error in this process (Van Geest et al., 2021). Amazon uses AGVs to implement their random storage policy for order fulfilment through picking technology where they are directed to the product using the optimised picking route selected by the system (Van Geest et al., 2021; Boysen et al., 2019).

2.9.3.2 Drones

Drones, also known as unmanned aerial vehicles, can also be used for efficient inventory management, particularly for tasks that are not accessible to humans and robots within the warehouse (Wawrla et al., 2019). A study presented by Wawrla et al., (2019) shows the application of drones within inventory management where they have systematically flown to inventory storage and conducted a scan for inspection on inventory quantity. Another application presented by Winkelhaus & Grosse (2022) of drones is where drones are being used for transportation of inventory within the warehouse.

2.9.4 Augmented Reality

Augmented Reality (AR) is an emerging technology that combines the physical world with virtual elements to create a new experience (Van Geest et al., 2021). The use of AR in inventory management systems requires wearable devices and hardware such as glasses, phones and tablets, which makes it more favourable to the staff to keep their hands free. AR devices such as smart glasses or mobile apps can be used to provide digital assistance to the staff in the warehouse guiding them to locations with directions, giving item details and picking instructions, reducing the human error rate. AR can also be used to assist in training staff using a simulated environment of inventory within the warehouse, optimising storage locations for inventory by providing warehouse layout visualisations, and visually comparing system inventory levels with physical inventory levels for accurate management of inventory data.

2.9.5 Dynamic Order Processing System

A dynamic order processing system (OMS) allows for orders to stream in real-time and add to both electronic picking routes assigned to staff or manually created picking routes. An order management system allows for the dynamic processing of orders where when a new order arrives, it analyses the availability of inventory and decides if it can be processed within the timeframe (Boysen et al., 2019). This helps the IMS ensure that efficient inventory levels are maintained for the timely fulfilment of orders meeting customer demand. It also maintains and updates inventory levels accurately when orders are processed, automatically marking inventory items as shipped in the system (Boysen et al., 2019).

2.9.6 Artificial Intelligence and Combining with IoT Devices

Artificial Intelligence (AI) involves intelligent machines that are competent to perform tasks that typically require human intelligence, for example, problem-solving, decision-making and learning (Singh & Adhikari, 2023). AI in inventory management systems has opened new avenues for enhancing inventory management processes. Its capacity to analyse and process large datasets and help forecast and predict trends has revolutionised traditional inventory methods/practices (Singh & Adhikari, 2023). The fusion of AI and Internet of Things (IoT) technologies offers transformative potential to the field of inventory management as it enables real-time tracking, predictive analytics and automated replenishment, increasing efficiency, accuracy and precision in managing inventory (Singh & Adhikari, 2023). The IoT devices, for example, RFID readers, collect and provide a continuous stream of real-time data and communicate this with the AI systems for analysis and decision-making regarding inventory levels. Building on these technologies, moves into other emerging trends such as machine learning, edge computing and blockchain technology, and these strategies also offer a reimagined future for inventory management. However, AI also introduces challenges such as data privacy and security due to the vast amounts of data being collected and processed. There is a risk of data breaches due to using cloud storage causing vulnerability to cyber-attacks, compromising data such as inventory products, prices and supplier contracts and causing operational disruptions resulting in inaccurate data (Singh & Adhikari, 2023). Technology requires a large investment in infrastructure to integrate with existing systems and provide large computational power for processing big data sets (Singh & Adhikari, 2023).

2.7.6.1 Machine Learning (AI model)

Machine Learning (ML) is a sub-branch of AI consisting of sophisticated algorithmic methods which enable computer systems to learn from data without the need to be specifically programmed (Chaudhary et al., 2023). The most common use of machine learning within inventory management is particularly around demand forecasting to identify ideal inventory levels. ML can analyse historical data quickly and learn patterns and trends, which improves the accuracy of demand forecasting. This therefore improves accuracy in decision-making resulting in efficiently meeting customer demand (Albayrak Unal et al., 2023; Singh & Adhikari, 2023; Chaudhary et al., 2023). Machine learning also improves stock visibility and optimisation of inventory levels, therefore avoiding stock-outs and dead stock (Pramodhini et al., 2023).

The types of ML algorithms include regression analysis, time-series analysis and neural networks that are involved within demand forecasting. Pramodhini et al., (2023) presented a study where machine learning algorithms achieved higher accuracy than traditional statistical models and inventory approaches. This resulted in reduced inventory costs and an efficient inventory management system. However, there is limited research on the application of machine learning, especially in SMEs, as most of the research focuses on ML use in large organisations where it is mostly employed as a stand-alone technology due to the lack of knowledge on integrating it with other technologies such as IoT and blockchain. Challenges of ML relate to data quality, cost and complexity, lack of staff knowledge on use due to ineffective training, security and privacy concerns, and adoption (Chaudhary et al., 2023).

Table 9 presents a recent study by Chaudhary et al., (2023) comparing the use of traditional inventory management techniques and inventory management using machine learning. It shows that traditional IM is often reactive, only relying on historical data for inventory decisions, with the use of manual data entry and analysis, which can also be prone to error. With the use of machine learning, IM is proactive and relies on real-time data and predictive analysis to make decisions more accurately. ML automates the analysis, which aids in reducing human error and saves time responding to patterns and trends to make important inventory decisions, such as ensuring inventory availability to reduce stock-outs, resulting in accurately maintained inventory data (Chaudhary et al., 2023).

Table 9 Comparison of Traditional Inventory Management with the Use of Machine Learning (Sourced from: Chaudhary et al.,2023)

Traditional Inventory Management	**Inventory Management with Machine Learning**
Reactive approach to inventory management, based on historical data and intuition	Proactive approach to inventory management based on real-time data and predictive analytics
Relies on manual data entry and analysis	Automates data collection and analysis using sensors, reducing errors and saving time
Limited visibility into supply chain and demand fluctuations	Provides real-time visibility into supply chain and demand fluctuations, allowing for rapid response
Fixed inventory levels and reorder points	Dynamic inventory levels and reorder points based on real-time demand and supply data
Limited ability to optimise inventory across multiple locations	Optimised inventory across multiple locations and supply chain partners, maximising profitability
Relies on static rules and heuristics for decision-making	Used advanced machine learning algorithms to identify trends and patterns in the data, improving decision-making
Limited ability to forecast demand and predict inventory needs	Accurately forecasts demand and predicts inventory needs reducing stockouts and overstock
Inefficient use of resources and higher carrying costs	Efficient use of resources and lower carrying costs maximising profitability

An example of an application of machine learning in inventory management is presented in a study by Singh & Adhikari (2023), where machine learning was used for drug management, providing enhanced traceability and efficient inventory management. This study highlights the current role of AI and IoT in ensuring the effective delivery of medicines (Singh & Adhikari, 2023). However, although these technologies are available and being used, there is a lack of extensive research that specifically addresses the use of these technologies in inventory management from different industries, and there is a need for further in-depth research showing the challenges and limitations of using this technology for efficient inventory management (Singh & Adhikari, 2023). Albayrak Unal et al., (2023) also explain that there is still a gap in the application of AI within inventory management as all types of applications have not yet been discovered, although from its current uses, it offers new possibilities, improved inventory management processes, efficiencies, and accurate predictions.

2.7.6.2 Edge Computing

Edge computing is another emerging trend that is being used within inventory management as this involves data being processed at the edge of the network closer to where it is generated, as opposed to in a centralised cloud-based system (Singh & Adhikari, 2023). Using edge computing means that changes to inventory data are processed immediately, reducing latency and enhancing real-time data processing capabilities, faster decision-making, and improved efficiency. This is vital for inventory management systems as this ensures immediate responses to the real-time updates in inventory levels, location and movement. Edge computing's localised processing capabilities enable a reduction in time required to analyse and act on inventory information such as, alerts for stock-outs or inventory data discrepancies (Singh & Adhikari, 2023).

2.7.6.3 Blockchain

Blockchain technology although in its infancy is part of AI and introduces a new dimension with significant potential to improve accuracy and efficiency within inventory management processes such as tracing and auditing (Groenewald & Kilag, 2024). Blockchain ensures transparency of transaction records whilst providing a secure history of inventory movements. Blockchain technology creates a decentralised ledger where all transactions or movement of inventory is recorded, and this information can be accessed in real-time. This allows transparency in identifying the exact location and condition of inventory at a time. In addition, blockchain technology conducts automated data entries on the ledger, reducing manual errors and inconsistencies, leading to real-time updates on inventory levels and reducing instances of stock-outs (Vaka, 2024; Groenewald & Kilag, 2024). The World Economic Forum (2019) notes that blockchain technologies can potentially transform inventory auditing practices, by providing a decentralised framework for recording and verifying inventory transactions securely, which helps reduce the risk of inaccurate inventory levels (Groenewald & Kilag, 2024).

To summarise, technology has a transformative role in upgrading traditional inventory management practices, using technologies such as barcoding, RFID, IoT, AI, robotics and blockchain. They offer extensive capabilities in terms of real-time visibility and predictive analytics to streamline the inventory management processes. Leveraging these technologies allows organisations to improve inventory data quality, reducing stockouts and improves operational efficiency (Vaka, 2024). The following section presents the literature outputs satisfying objective 2 and further explains the rationale for using a socio-technical lens to view an IMS satisfying objective 1.

2.10 Rationale for Using Socio-Technical Lens to View An IMS

This section presents a conceptual model of the challenges and CSF identified from the literature and mapped to OPPT. This provides the basis for a rationale, further explaining and justifying the use of a socio-technical lens to view an IMS.

2.10.1 Conceptual Model Visualising Literature Findings

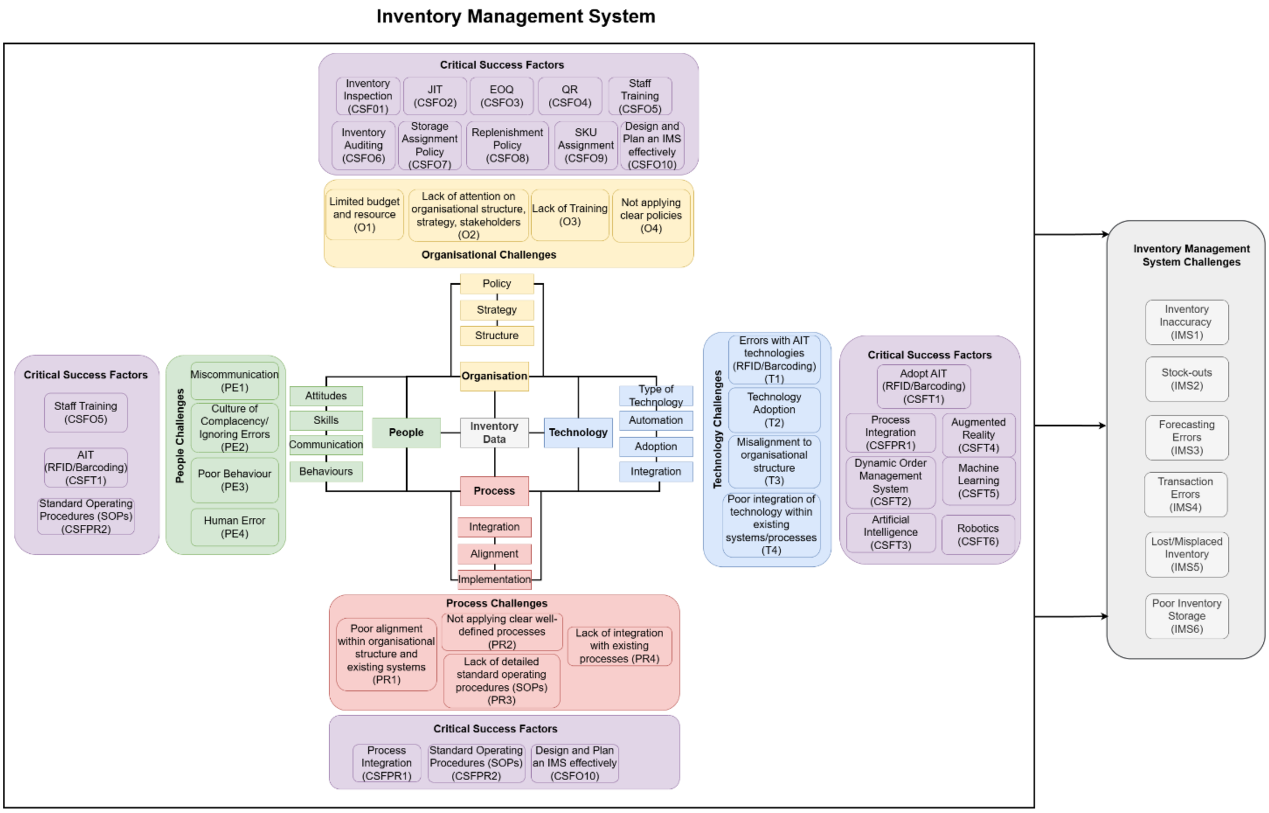

Figure 12 Conceptual Model

Figure 12 presents the conceptual model developed to conceptualise the literature findings. The inventory management systems challenges and causal factors were categorised into the four selected elements in the developed socio-technical approach: organisational, people, process and technology in Section 2.5.6, to ensure a holistic view of the challenges faced in IMS. The critical success factors were mapped to the corresponding challenges they aim to address, to show the relationships between them.

The causal factors within organisational elements category are placed within the large yellow outlined box, linking the causal factors within people, process and technology element categories as they all occur within the organisations. The process and technology causal factors are linked to the technical perspective of the IMS. Attitudes, skills, communication and behaviour are linked to the social perspective and are classed as subsets of the people therefore, the people causal factors have been assigned here. The inventory management system challenges are in grey and placed central to all OPPT elements, showing how the organisational, people, process and technology being challenges in their own rights, act as causal factors that contribute and cause the inventory management system challenges to happen in the IMS as a result causing inaccurate inventory data.

In reviewing the IMS challenges, their causal factors and the CSFs, it is noticed that the CSFs are domain specific within IMS, however causal factors that are mapped against the OPPT areas can be generic challenges faced within other information systems. This can be explored as future work in reviewing the applicability of the causal factors within the OPPT elements in other domains.

2.10.2 Matrix Mapping Showing Relationships Between IMS Challenges, Their Causal Factors and Critical Success Factors to Identify Relationships

This section presents the mapping of the IMS challenges, their causal factors and the critical success factors as found in the literature to identify their relationships and highlight the interrelatedness among them. Understanding the correlation between each CSF and the challenges, enabled the allocation of the corresponding CSFs to the relevant challenge it aims to address. This further supports the need for a socio-technical approach to holistically view all OPPT elements as interdependent elements. The relationships identified between the challenges in the IMS and OPPT elements with the relevant CSFs show that errors experienced or changes made in one element will impact another. This reflects the view of Hughes et al., (2017) that work systems can only be completely understood and improved if these elements are treated independently. In addition, emphasising that changes to one part of the system can necessitate changes to another part. Improvements to a work system driven solely by technological innovation, fail to consider the way that humans interact with these technologies reducing their likelihood of success. Applying an STS approach has been shown to lead to successful system improvements and organisational change within a work system (Hughes et al., 2017). Figure 13 presents the matrix mapping of relationships between the elements. The codes used within this mapping are referred to in the Appendix 3.

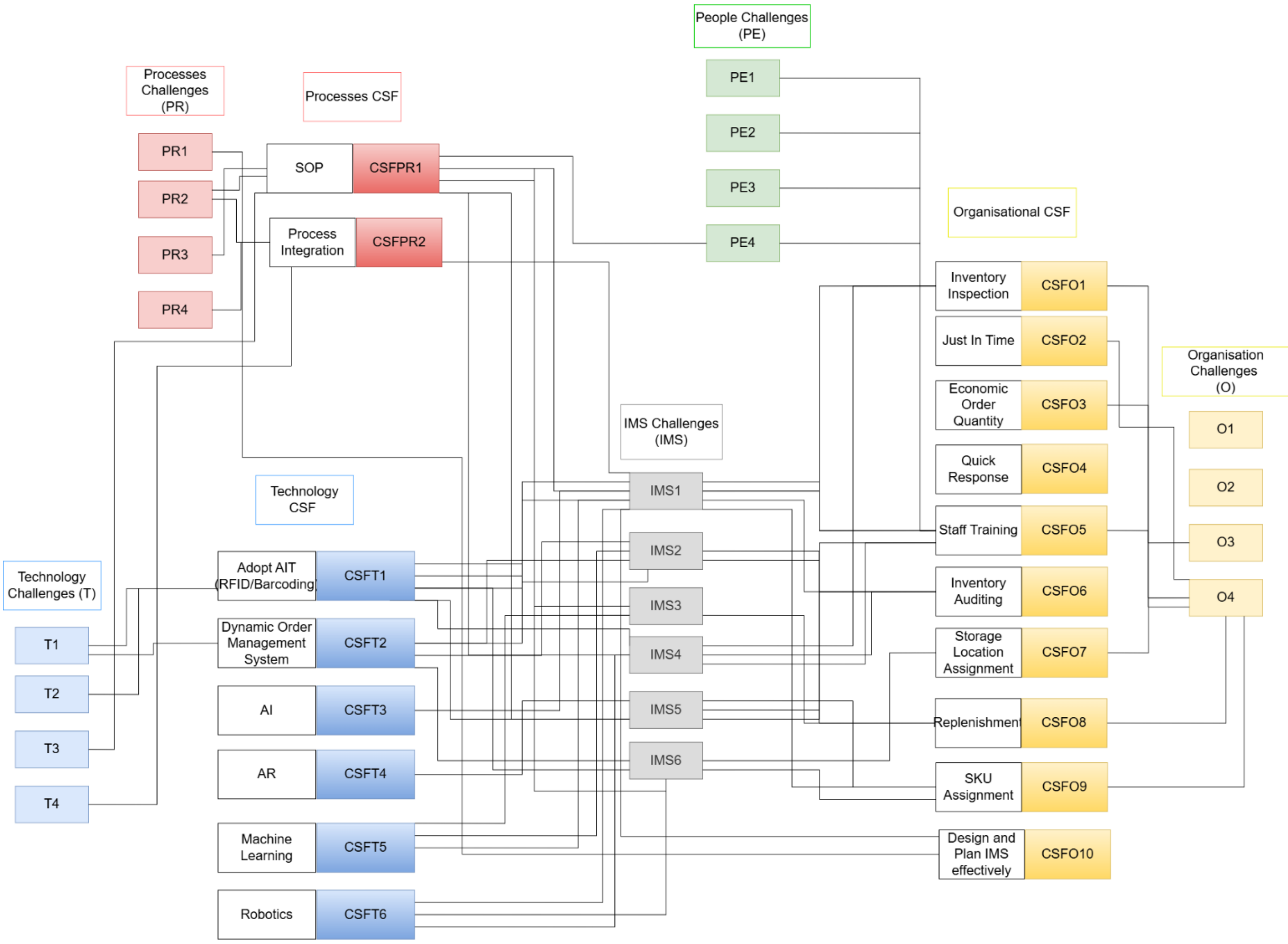

Figure 13 Matrix Mapping of Relationships Between IMS Challenges, Their Causal Factors and CSFs

2.10.3 Socio-Technical Systems Approach

Socio-technical systems theory emphasises joint optimisation of social and technical components is needed to improve systems performance (Emery & Trist, 1978). Section

2.9 revealed that although technologies can be used to improve the operation of an IMS, problems continue to arise when advanced technologies are implemented. For example, an organisation that adopts a fully automated IMS with the use of barcoding/RFID and/or machine learning algorithms, may still have inaccurate inventory data due to other challenges in the IMS not being addressed. Implementing technology, does not completely resolve the problem of inaccurate inventory data. This is because human errors may still occur due to ineffective technology adoption or lack of skills and training in understanding how to use the technology. Challenges across the OPPT areas will therefore remain, hindering the performance of the IMS and resulting in inaccurate inventory data.

This reinforces the findings of the literature discussed in Section 2.4.1 that identified the need for a holistic approach to be adopted to improve data quality in inventory management systems. However, there has been a lack of further research to indicate that the views of Vries (2020), Winkelhaus & Grosse (2022), Munyaka & Yadavalli (2022), and more recently, Groenewald & Kilag (2024) have been taken forward and applied to improve inventory data quality and operational performance of IMS. This research therefore addresses the research gap of how to adopt a socio-technical systems approach to improve inventory data quality. The thesis adopts a socio-technical approach of OPPT and uses this as a holistic STS lens to view an IMS, working towards joint optimisation of the organisational, people, process, and technology elements. Figure 9 provides an STS view of inventory management systems to ensure joint optimisation of each of the four OPPT elements to improve inventory data quality.

2.11 Chapter Summary

Chapter 2 presents a literature review of the core concepts of this research: inventory management, inventory management systems, IMS relationship with warehouse management system, SMEs, e-commerce retail and socio-technical systems. The IMS challenges and their causal factors, CSFs implemented and technologies used to aid in effective IMS have been defined (objective 2). The chapter justifies adopting the view of IMS as a socio-technical system supporting the view that IMS challenges need to be addressed holistically. A model of socio-technical view of IMS (objective 1) has been developed and presented in Figure 9 in Section 2.5.6. This model was used to categorise the causal factors of IMS challenges and CSFs into the OPPT elements as presented in Figure 12 in Section 2.8.1. This model reinforces a rationale for using a socio-technical systems lens to view an IMS, emphasising the need for joint optimisation of technical and social elements to improve inventory data. From the IMS challenges and their causal factors, it was identified that inventory data is at the core of the IMS challenges, substantiating that inventory data quality needs improvement. The following chapter outlines the methodology to be followed to improve inventory data quality in inventory management systems.

3 Research Methodology

3.1 Introduction

The chapter presents the adopted philosophical framework that underpins the research design and outlines the rationale behind the selected research methods. It articulates the selected approach to theory development, methodological approach, data collection procedures and data analysis methods integral to this research.

3.2 Research Onion

The research onion provides a systematic approach to designing and conducting a research study in 5 layers, as presented in Figure 14 (Saunders, 2009). This is used to structure the discussion of the research design in the following sections.

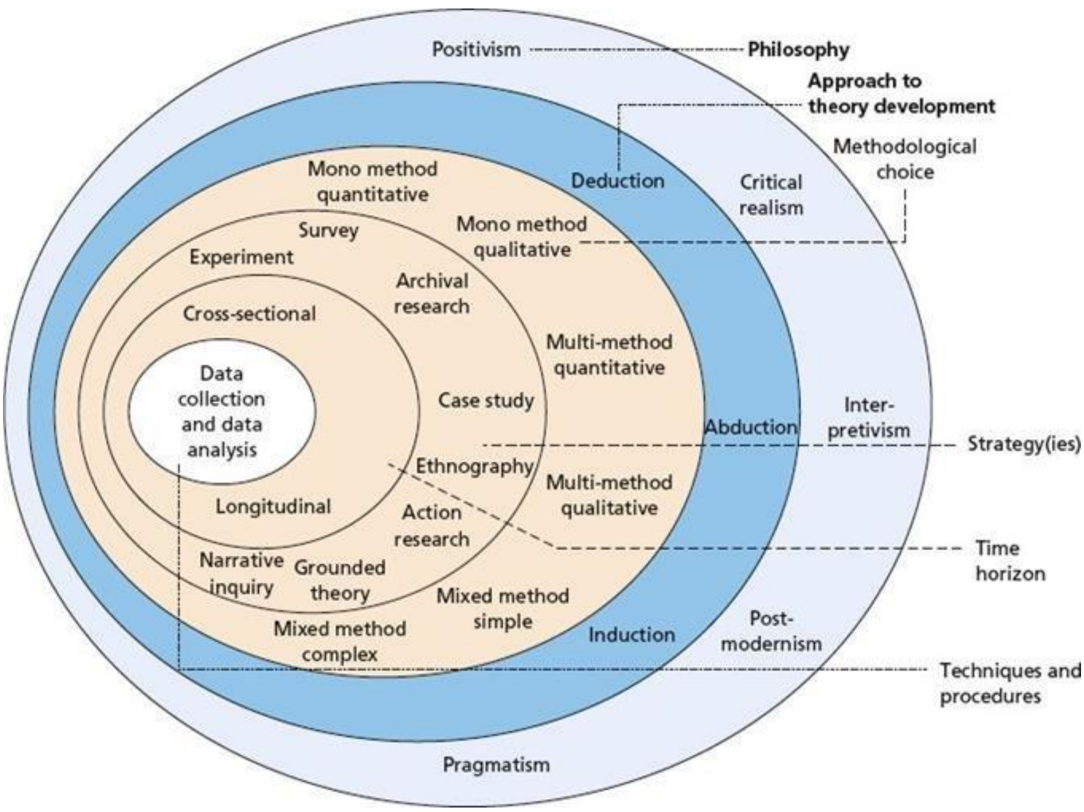

Figure 14 Research Onion (Sourced from: Saunders, 2009)

3.3 Research Philosophy

Research philosophy refers to the set of beliefs and concepts about the development of knowledge and the nature of the knowledge being investigated in a research study (Saunders, 2019). Questioning self-thinking and actions helps develop the appropriate research philosophy, which will inform the choice of methodology, strategy, and data collection techniques (Saunders, 2019). Identifying the appropriate research philosophy is important as it influences the research practice and helps explain why approaches were selected for use in the research (Creswell, 2009). Creswell (2009) outlines that the foundation of research is establishing a '*philosophical worldview'*, also referred to as paradigms, epistemologies, and ontologies or research methodologies. Saunders et al., (2009) explain how the different philosophical assumptions both epistemology and ontology, guide research.

3.3.1 Ontology

Ontology relates to the values a researcher holds about what can be known as real and what an individual believes to be factual (Ryan, 2018). Jackson (2013) explains ontology as the philosophical study of the nature of reality and how there can be differing perceptions of what is known. Scotland (2012) states that there is an interpretive paradigm of ontology where reality is subjective, socially constructed and differs from person to person, where it does not question ideologies but accepts them. It is understanding the phenomenon from an individual's perspective, understanding people's interpretations and meanings and investigating the interaction between consciousness and phenomena (Scotland, 2012). This study adopts an interpretive ontology as it views reality as being shaped by human interpretations, in this case emphasising the importance of collecting views of IMS in SMEs. A case study was later adopted to engage with an SME and gather their views of improvements implemented.

3.3.2 Epistemology

Epistemology is the philosophical study of knowledge and the grounds on which something is believed to be true. Epistemological assumptions are central to understanding knowledge and concern how knowledge can be created, acquired and communicated (Jackson, 2013; Scotland, 2012). Jackson (2013) explains that a researcher's ontological position links directly to the epistemological perspective, where the ontological perspective relates to the reality of the world, and the epistemological perspective relates to the knowledge of that world. The epistemological stance must align with the ontological assumptions about the differing interpretations of IMS. This study is rooted in an interpretivist stance, which aligns with the research focus on understanding how SMEs perceive and interpret IMS, as reality is subjective and is a socially constructed phenomenon shaped by humans.

3.3.3 Philosophical Paradigms

Four major philosophies are outlined by Saunders et al., (2009): positivism, interpretivism, critical realism, and pragmatism. The chosen paradigm should be in place to help guide the research methods and the analysis of the study (Ryan, 2018). It is important to understand the different philosophical paradigms, their origins, and principles so that a researcher can decide which is appropriate based on the research context and inform the study's design, methodology, and analysis (Ryan, 2018). Scotland (2012) argues that each paradigm is inherently based on ontological and epistemological assumptions. Therefore, they have differing perceptions of reality and knowledge, reflected in their methodology and methods, thus underlining that the philosophical underpinnings of each paradigm can never be empirically proven or disproven (Scotland, 2012). The following sections outline four philosophical paradigms and discuss the adopted research philosophy for this study.

3.3.3.1 Positivism

Positivism holds the ontological position of realism, which is the view that objects and a discoverable reality exist independently of the researcher (Scotland, 2012). In agreement, Rehman & Alharthi (2016) state that positivism assumes that reality exists independently of humans, where it is not mediated by the senses. Researchers act as objective observers to study phenomena that exist independently. Positivism, a scientific paradigm, outlines that its methods often generate quantitative data such as inferential statistical analysis, tests, and surveys. However, interpretivists and critical theorists have heavily criticised this paradigm, stating that although its scientific methods are appropriate for studying natural phenomena, they fall short when used to study individuals and social phenomena (Rehman & Alharthi, 2016). This is due to the ontological positioning and epistemological stance where reality is objective and independent of human perception, overlooking human interpretations and social context. Therefore, it differs from interpretivism, which bases reality on human perceptions.

3.3.3.2 Interpretivism

Interpretivism is a *'dominant philosophical approach'* that portrays social reality through the eyes of those involved, taking into account multiple perceptions, meaningful interpretations and understanding of what may be real (Chowdhury, 2014; Ryan, 2018). In agreement, Scotland (2012) explains that interpretivism consists of the view that reality is subjective, individually constructed and differs from person to person. It involves grasping the phenomenon through an individual's perspective and exploring how people interpret and assign meanings whilst examining the relationship between consciousness and phenomena (Scotland, 2012). Examples of interpretive methodology relevant to this study are case studies, which involve in-depth study of events or processes over a prolonged period, open-ended interviews and observations (Scotland, 2012). This is in high contrast to positivism, as this notion regards knowledge in an objective manner and sees only one single reality (Ryan, 2018). Research is classed as positivist if there are quantifiable measures of variables and hypothesis testing. In contrast, interpretive research outlines reality is socially constructed through constructions such as language and shared meanings and these perceptions can be influenced (Myers, 1997).

3.3.3.3 Critical Realism

Critical realism was developed by Bhaskar in the 1970s as an influential philosophy of the natural and social science studies in various areas (Sorrell, 2018). Critical realist perspectives are not intended to predict or interpret, but to explain, developing empirically supported theories and hypotheses regarding how, why and under which conditions particular phenomena occur (Sorrell, 2018). Saunders (2009) explains that critical realism focuses on explaining what is seen and experienced within the underlying structure of reality that shapes the observable events occurring. It focuses on what is experienced as the 'empirical', which are manifestations of things in the real world rather than the actual reality of those things. Sorrell (2018) argues that critical realism cannot be used to assess the validity of theoretical claims; rather, it can be used to evaluate their ontological and epistemological assumptions and select the appropriate methodologies for investigation.

3.3.3.4 Pragmatism

Pragmatism focuses on making a difference in organisational practice, where concepts are only relevant when they support action-led movements (Saunders, 2009). Reality matters to pragmatists as only practical ideas and knowledge are valued for enabling successful actions. Selecting this paradigm results in research that may have considerable variation in being subjective or objective, as researchers are more interested in practical outcomes than abstract distinctions. Additionally, research begins with a problem and thus aims to contribute practical solutions that can help inform future practice. Undertaking pragmatist research would mean that the research problem, addressing the research questions, and emphasising practical outcomes are the most important factors (Saunders, 2009). Maarouf (2019) argues that pragmatism refers to the notion of "what works" and is oriented towards solving practical problems in the real world rather than considering assumptions about knowledge. Additionally, pragmatistic research should be designed and conducted in the best interest of the research, which serves to answer the research questions regardless of its underlying philosophy (Maarouf, 2019; Kaushik & Walsh, 2019). Table 10 presents a comparison of research philosophies on their ontological and epistemological characteristics, including typical research methods used.

Table 10 Comparison of Research Philosophies (Sourced from: Saunders, 2009)

Philosophy	*Ontological characteristics (nature of reality)*	*Epistemological characteristics (how and what is acceptable knowledge)*	*Typical Methods*
Positivism	One true reality that is real, external and independent Objective.	Follows a scientific method Observable & measurable facts.	Deductive, Large samples, Typically quantitative, Quantifiable measure of variables, Hypothesis testing.

Interpretivism	Multiple meanings, perspectives and interpretations of realities Socially constructive Rich, complex and holistic.	Focus on narratives, explores different perceptions and interpretations Contributes new understandings and worldviews.	Typically inductive, Small samples, In-depth investigations, Qualitative method of collection and analysis, Range of data can be interpreted.
Critical Realism	Reality is external and independent but not accessible through observation and knowledge of it.	Understand the social constructions Focuses on underlying causes and mechanisms.	Retroductive. In-depth historical analysis of social and organisational structures. Use a range of methods.
Pragmatism	Reality is the practical effects of ideas.	Practical meaning of knowledge in specific contexts Focus on making a difference to organisational practice.	Range of methods, quantitative, qualitative, mixed, multiple method, Practical solutions to inform future practice.

3.4 Adopted Research Approach

This study adopts interpretivism as its chosen paradigm and research approach due to the view that reality is socially constructed and shaped by human interpretations. As inventory management systems are socio-technical systems, the focus is on understanding the interplay between technology, people and the organisational processes. It is emphasised from the literature in Chapter 2 that accurate inventory data is not solely determined by technological elements but also by human interactions and organisational processes. Interpretivism, rooted in the belief that reality is socially constructed, shaped by human interpretations and context-dependent, aligns with the socio-technical nature of this study. Interpretivism prioritises understanding the key social dimensions in this research, such as attitudes, skills, communication and behaviours and their impact on inventory data and IMS operational performance. Regarding multiple author perceptions, Rehman & Alharthi (2016) explain that the existence of multiple knowledge is accepted by acknowledging that different researchers bring different perspectives to the same issue. This relates to this research by presenting the key authors' (Vries, 2005,2007,2013 and 2020; Muchaendepi et al., 2019; Winkelhause & Grosse, 2022; Munyaka & Yadavalli, 2022) perspectives on viewing IMS holistically using a socio-technical perspective that both the social and technical elements must work together to be effective. The clarification of philosophical underpinning is useful for research design to make informed choices regarding the methodology and methods to be used in the research (Jackson, 2013).

3.5 Methodological Choice

Research methodologies are usually identified as either qualitative or quantitative, however other identifications also exist presented in Figure 15. According to Duffy & Chenail (2009), qualitative and quantitative research methods can generate sound and meaningful research findings providing that the researcher has an appreciation for ensuring that there is coherence in working with a particular research philosophy. Morgan (2013) states that qualitative and quantitative methods involve more than the standard methods used in the research. They are not intrinsically associated with one kind of research or another. Therefore, it is important to understand not which methods are used to generate data but '*how'* they are used and for what purposes. Scotland (2012) defines methods as the specific techniques and procedures used to collect and analyse data, either qualitatively or quantitatively. Additionally, the methodology is a plan for implementing the chosen philosophy, which involves using a selection of methods concerning why, what, when, and where in data collection and analysis (Scotland, 2012).

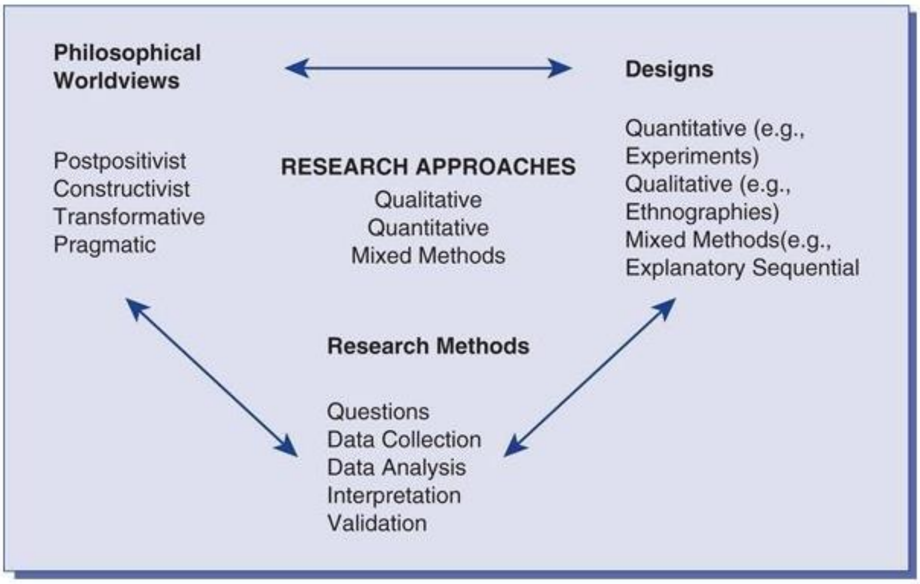

Figure 15 A Framework for Research- The Interconnection of Worldviews, Design and Research Methods (Sourced from: Creswell, 2014)

3.5.1 Quantitative Research

Quantitative approaches are useful when the study mainly focuses on static characteristics where variables can be evaluated through measurements, predominantly focusing on numerical data from data collection or analysis (Kaplan & Maxwell, 2005; Saunders, 2009). Morgan (2013) describes quantitative research as comprising a deductive purpose, beginning with theories and hypotheses and then evaluating through observation. This results in three basic distinctions: quantitative research is typically deductive, objective, and general (Morgan, 2013).

3.5.2 Qualitative Research

The strengths of qualitative approaches lie in their usefulness for understanding the meaning and context of the phenomena studied and allowing participants to freely express their views and not be bound by fixed-response questions, which are mostly occurrent in quantitative approaches (Kaplan & Maxwell 2005). Morgan (2013) describes qualitative research as comprising of an inductive purpose, starting with observations and then using these to create a theory or generate hypotheses. This results in three basic distinctions: qualitative research is inductive, subjective and contextual (Morgan, 2013).

3.5.3 Mixed Method Research

The mixed method research can achieve what would be more difficult to accomplish by solely operating within the traditional methods: qualitative or quantitative research (Morgan, 2013). Qualitative and quantitative methods are no longer seen as separate and discreet methods but represent two ends of a continuum, where mixed method research is in the middle (Maarouf, 2019). Mixed method research combines qualitative or quantitative methods, and Maarouf (2019) states that this enables a complete understanding of the research problem rather than only using one specific method, leading to an overall understanding of the research phenomena. Maarouf (2019) and Migiro & Magangi (2011) state that the advantage of using mixed-method research is that there are complementary strengths, meaning that it uses the strengths of one method to enhance and support another, enabling triangulation. The purpose of this is to enrich the research results by using different methods of data collection and analysis to study the same research phenomenon so that a more transparent overall understanding is achieved. However, mixed method research also has criticisms, stating that both quantitative and qualitative cannot be mixed due to the different epistemological and ontological assumptions each one follows (Fakis et al., 2014). Some researchers believe that only using one method is limited for research problems and that combining these improves research quality. There are three different research designs for the mixed-method research:

- Convergent parallel mixed method: The researcher collects both quantitative and qualitative data simultaneously and then integrates the results to obtain a comprehensive analysis of the research phenomenon.
- Explanatory sequential mixed method: The researcher conducts quantitative research initially and then qualitative research, where the qualitative research provides further explanation for the quantitative results.
- Exploratory sequential mixed method: The research starts with qualitative research, then conducts the quantitative research, showing that data collected from the qualitative phase could be used to build a new instrument or to choose variables for the next quantitative phase (Migiro & Magangi, 2011).

[1]3.5.4 Adopted Methodological Approach

This research adopts a qualitative research method to explore how SMEs perceive IMS and how inventory data quality can be improved. The complex, socio-technical nature of IMS necessitates a contextual and socially constructed understanding that cannot be captured purely using quantitative measures. As the research is deeply rooted in interpretivism as explained in Section 3.4, qualitative methods allow for in-depth exploration of participant perspectives of IMS. This helps to fully comprehend the research problem and achieve the respective research objectives and, ultimately, the research aim.

Referring to Figure 17, which presents the research design, the research activities consisted of a literature review and the necessary field work, such as conducting semi-structured interviews to validate the literature findings and obtain rich data from SME participants regarding their interpretations of IMS.

Using qualitative research methods for data collection and data analysis enabled a richer insight into the research phenomena (Maarouf, 2019). Maxwell (2012) summarises qualitative research as inductive and open-ended, relying on textual and visuals rather than numerical data with its prime goal of particularly understanding and not generalising across perspectives. Maxwell (2012) defines three main features of qualitative research:

1. Qualitative research provides a better understanding of different meanings and perspectives as opposed to pre-conceived ideas
2. Perspectives are shaped by influencing aspects like social, physical and cultural
3. Importance of understanding the specific processes that are involved in maintaining or changing this phenomena/theory.

3.6 Research Strategy and Techniques

3.6.1 Data Collection Techniques

Data collection involved the literature review and the semi-structured interviews. The literature provided an overview of the research topic of IMS and their challenges, causal factors, CSFs and technologies. This helped formulate the interview questions. The primary data collection was conducted through semi-structured interviews to validate the literature findings.

3.6.1.1 Literature Review

A literature review *"acts as a stepping-stone towards the achievement of the study's objectives"* (Wanjohi, 2012). The importance of conducting a literature review is that it provides a solid background, ensuring awareness of the field and creates a firm foundation for evolving knowledge in a specific subject area, as stated by Webster, (2002). Objectives 1 and 2 were achieved through a literature review presented in Chapter 2. The literature explores socio-technical systems and their link to IMS, resulting in a socio-technical view of an IMS model developed in Section 2.5.6 in Figure 9. Additional literature identified IMS challenges, causal factors, CSFs and technologies, which were categorised in OPPT and mapped to Figure 9 to result in the conceptual model which conceptualises the literature findings presented in Figure 12.

3.6.1.2 Semi-Structure Interview

A semi-structured interview was adopted as the data collection method to validate the literature findings, identify any additional IMS challenges and CSFs and understand the state of IMS in practice. Barkat (2022) states that interviews offer a different way of exploring people's perspectives and allows the researcher to gain deep understanding of their views. Interviews allow for in-depth data collection using mostly open-ended questions to be answered by study participants in their own words (Erzberger et al., 2003). Elaborating on the open-ended questions allowed for more insight into understanding a topic, which can be missed when using a quantitative method (Migiro & Magangi, 2011). Semi-structured interviews were selected to validate the literature findings in order to achieve objective 3. Rich primary data was collected from the inventory managers to gather a detailed understanding of differing interpretations of IMS, the extent of the IMS challenges and the overall performance of their IMS.

3.6.1.3 Case Study: Testing

As the study adopts a qualitative research method, the case study strategy was selected from the strategy layer of Saunders research onion. Case study research builds on an in-depth, contextual understanding of the case, relying on multiple sources of data (Yin, 2003). Creswell (2007) and Yin (2003) state that case study research is a qualitative approach where the investigator explores a bounded system over a period of time through in-depth data collection, which can involve many data sources such as observations, interviews, audio files, reports and document analysis. It emphasises that a case study can be holistic as it addresses the research phenomenon in the real-world context and can be used in evaluations as a research method (Yin, 2009). A semi-structured interview within a case study was used to collect data regarding the context of the inventory management system. The case study includes quantitative data through document analysis to measure the impact of the framework.

3.6.2 Data Analysis Technique

The following section outlines the data analysis selected for this research, applying soft systems methodology.

3.6.2.1 Soft-Systems Methodology Analysis

Soft systems methodology (SSM) was developed by Peter Checkland in the 1980's to bring together new knowledge and insights of system theory in situations involving humans (Basden & Harper, 2006). Peter Checkland and Brian Wilson, used action research in the development of SSM, to identify and improve 'soft' unstructured problematic situations, allowing the possibility of capturing the necessary change (Burge, 2015; Mehregan et al., 2012). SSM allows for the deep understanding of real and conceptual aspects of analysis involving both the technological (hard) systems and the human (soft) systems elements and helps in analysing their integration (Checkland & Poulter, 2007; Nugroho et al., 2024).

SSM recognises that stakeholders will have different worldviews, so the models used in SSM help reflect these varied perspectives (Liu, 2012). This allows problems to be understood by analysing the organisational context and the constraints on improving the problematic situation (Memon et al., 2016). Its systemic methodology focuses on the whole rather than the parts. It is used for tackling real-world problematic situations where different perspectives of the problem situation can be understood (Mehregan et al., 2012). Soft systems methodology comprises stages that emphasise problem identification, problem structuring and problem improvement, as presented in Figure 16 in the following section (Memon et al., 2016).

3.6.2.2 Stages of Soft System Methodology

The traditional SSM model consists of seven distinct stages with two types of activities: real-world activities and systems-thinking activities (Mehregan et al., 2012). The seven stages are presented in Figure 16.

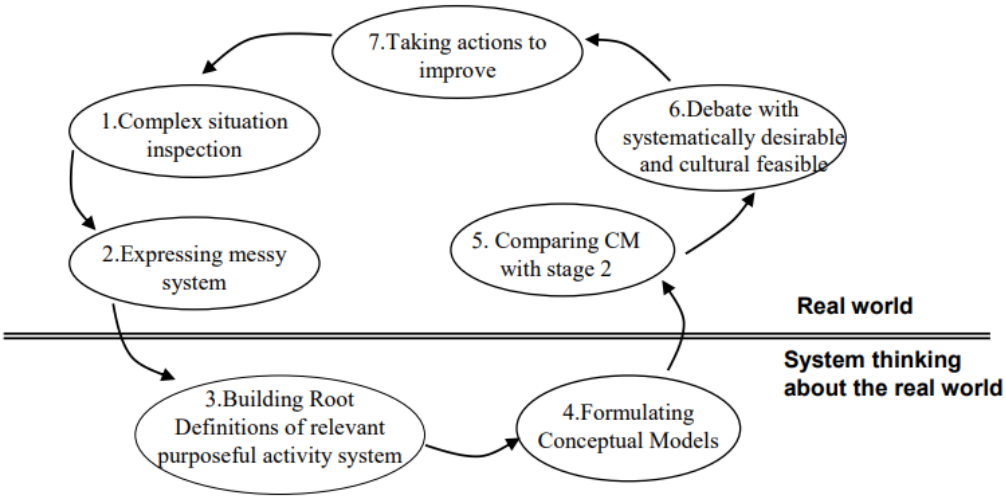

Figure 16 Seven stages of SSM (Sourced from: Wang et al., 2015)

Mehregan et al., (2012) explain the stages of soft systems methodology, where firstly stage one and two entail investigating the problem situation and expressing it as a rich understanding. This later developed into expression as a rich picture, a physical diagram visualising the problematic situation using symbols and drawings. Either quantitative or qualitative research methods can be used to elicit results that inform the creation of a rich picture. Stage three starts to formulate the root definitions, which describes the notional system needed to address the problematic situation. The CATWOE helps to understand the transformation needed, by considering who is in it, who is taking part and who could be affected. Stage four develops the conceptual model that identifies the main purposeful activities needed to perform the transformation outlined in the root definition. Stage five is where the models created are compared with the real world, igniting discussions by stakeholders to understand a mutual consensus of the proposed changes to improve the problematic situation. Stage six highlights identifying changes to the real-world system and assessing the feasibility of the changes. Finally, stage 7 involves confirming and carrying out the changes identified from stage six into real-life practice. Mehregan et al., (2012) also argue that it is not necessary for all stages of SSM to be applied as selected stages can be utilised depending on the problem outcome and time horizon.

3.6.2.3 Rich Picture Analysis

Rich pictures allows a comprehensive visual representation of a problem situation to be presented, which reflects multiple viewpoints, relationships and conflicting areas (Monk, 1998 and Burge, 2015). Rich pictures investigate and visually map out the problem situation, and this is the first stage of SSM (Mehregan et al., 2012). Kado (2023) states the method of drawing rich pictures for analysis enables complex social phenomena to be captured resulting in deeper understandings and insight in the data that an interview alone may not capture. Rich pictures capture different perspectives in complex situations including people, places, emotions, viewpoints, relationships and cultural context and overall allows for deeper and richer exploration of the perspectives (Kado, 2023). Rich pictures were used to analyse the interview data collected in this research. Vries (2020) states that rich pictures help map out underlying mechanisms regarding conflicting interests and the problem situation to structure the evaluation process and analysis of conflict (Ackermann, 2024). Using rich pictures for interview analysis is useful as the rich picture itself can be used to examine influencing factors, identify causes and strategies to improve a situation all through using icons, symbols and arrows to visually communicate emotions, culture and conflict (Parrott, 2019). Either quantitative or qualitative research methods can be adopted to explain the problem situation and to allow for adequate information to be collected that would enable the production of the rich picture (Mehregan et al., 2012).

Interviews can be analysed using some methods such as, coding analysis, thematic analysis narrative analysis. Coding is divided into 3 types: open coding where each part of the interview is studied to identify relevant categories and label it with a relevant code. Axial coding is where the categories once defined are refined and interconnected and selective coding is where the main/central category that ties all the theory together is identified and then related to other categories (Gibbs, 2007). Coding analysis can be conducted using data analysis softwares such as NVivo, making it easier for researchers working with large amounts of interview data. Thematic analysis identifies, analyses and interprets key patterns of meaning (themes) which are formed within a data set (Harper, 2011). Narrative analysis is mostly concerned with understanding how and why people talk about subjects in a certain 'narrative' manner similarly to narrating a life story.

In this research, rich picture analysis has been selected to analyse the semi-structured interview data from the initial primary data collection with inventory managers. Rich picture analysis provides a way to synthesise qualitative data, simplifying the process to identify key themes, relationships, interpretations and highlight problematic situations. In addition, this method of analysing interview data helps the researcher move beyond fragmented interview responses and see clear patterns across the multiple interviews. The following section discusses the CATWOE model and Root Definition tools of SSM.

3.6.2.4 CATWOE Model and Root Definition

The elements of the mnemonic CATWOE are Customers, Actors, Transformation process, Weltanschauung (Worldview), Owner and Environmental factors. The CATWOE is made up of these six elements which when completed correctly focuses on building the root definition of the proposed system (Basden & Harper 2006; Memon et al., 2016). If any of these elements are not completed, it will result in an impoverished root definition (Basden & Harper 2006). Memon et al., (2016) summarises the describes customers as stakeholders affected by the transformation. Actors which are the people who will be performing the transformation activities. Transformation process states what is to be changed. Worldview is stating the perspective in which the transformation is purposeful. Owner is the person who controls the transformation process and finally environmental factors are anything external factors that impose constraints on the execution of the transformation process. CATWOE is developed from the rich picture analyses, capturing the worldview needed to formulate the root definition. The root definition is informed by the key transformation process outlined in the CATWOE. It is a concise definition of a notional system that describes the system overall, what the system does, what the purpose is, what the output is, who will be involved and who will be affected (Liu 2012; Mehregan et al., 2012). The next section discusses the Conceptual Model tool used within SSM.

3.6.2.5 Conceptual Model

Conceptual models are formed to represent the main purposeful activities required to satisfy the root definition (Mehregan et al., 2012). Burge (2015) states that conceptual models are not the real world that we experience but are logical models indicating what it could be, as it shows what “good” looks like compared to the real-world and this helps to identify where changes could be made. The conceptual model is compared with the real-world situation to inform discussion of what changes could be made in the real world to improve the problem situation (Mehregan et al., 2012; Ackermann 2024). Simply, SSM understands the unstructured messy problems of the real world caused by people’s multiple viewpoints and creates rational logical conceptual models for comparison to make clear recommendations in response to the problem (Burge, 2015).

In this research, the CATWOE and root definition will be used to inform the development of the conceptual model to improve the operational performance of IMS. The conceptual model developed will help to inform the design of a framework to improve data quality in IMS. The following section discusses the philosophical underpinnings of SSM.

3.6.2.6 Philosophical underpinnings of Soft Systems Methodology

The philosophical underpinnings of SSM are that it is grounded in interpretivism, which is a strength and defining characteristic of SSM (Holwell, 2000). Holwell (2000) explains there are three features of SSM linking it to an interpretive approach, which are the use of ‘system’ as a construct (or more recently as an epistemological device), recording the value of the conscious abstraction that comes from models used from above and below the distinction line of the real-world and system thinking situation shown in Figure 16, and finally, the reflection of social, political and historical aspects attached to a problem. SSM is widely used as a qualitative research methodology based on systems thinking theory and action research as human involvement introduces complexity, resulting in unstructured problematic situations (Aryee & Hansen, 2022). SSM embraces multiple interpretations and derives meaning from social interactions. The SSM tools provide a structured way to explore complex, problematic situations and multiple perceptions. SSM is used in this research at it is an interpretivist approach that explores multiple perspectives and social interactions in structuring problem situations, which aligns with the socio-technical stance adopted. In this research, soft systems methodology was employed utilising a consensus-driven approach to structure views of IMS in practice to construct a cohesive conceptualised system to improve IMS performance. Soft systems methodology was selected to analyse the initial interview findings, and a case study with a semi-structured interview will be conducted for the testing and evaluation of the framework.

Considering the interpretivist philosophical stance underpinning this research, it is acknowledged that the adoption of SSM requires a degree of interpretation from the researcher. It is acknowledged that the development of the rich pictures requires visually representing participants narratives, which to some degree may have been influenced by the researcher's self-understanding, assumptions and professional interpretations especially with the IMS challenges faced. Although every effort was made to remain consistent to the participants viewpoints, it is also recognised that the key elements and their representation within the rich pictures can introduce subjective bias. Rich pictures are a subjective visual representation of complex, human-centred problem situations which represent multiple viewpoints, tensions and relationships within. Rather than attempting to eliminate the subjectivity, the interpretivist approach embraces it as a valuable component of contextually understanding the problem situation. This aligns with the interpretivist view that reality is socially co-constructed between the researcher and participants rather than discovered as a fixed reality. Similarly, the subsequent stages of SSM in the development of the CATWOE, root definition and conceptual model required interpretative judgment in refining context-specific challenges within the systemic elements of the conceptual model.

To enhance methodological transparency and enable potential replication of the implementation of SSM, the approach was clearly documented, detailing all stages of SSM, with consistent application of the core SSM principles across all five SME interviews. Each stage of SSM implementation was rooted in the primary data collected from the semi-structured interviews. A reflective stance was also maintained throughout the data analysis process, ensuring awareness of any assumptions or interpretations, keeping each analysis grounded in the data collected. Considering future researchers, it is encouraged to adopt a transparent process of interpretation grounded in the data collected, actively engage in reflexivity and, where possible, involve the participants in validating the representations to mitigate levels of subjectivity. Particularly analysing interview data using rich pictures, firstly requires in-depth semi-structured interviews with themed and open-ended questions to allow the collection of rich and narrative responses. This allows the problem situation and multiple perceptions of IMS within the SME organisations to be analysed and understood. After conducting each interview, a narrative summary is written to capture the key points, themes and contextual details by each SME organisation. This summarisation step acts like a bridge between the raw interview summaries and the development of rich pictures for visual in-depth analysis. Based on each interview summary, a rich picture can then be drawn to visually represent the SME organisation's context, problem situation, perceptions, challenges and relationships. The rich pictures help capture the complexity and interconnectivity of the themes and provide a subjective visual synthesis of each of the interview's narratives.

3.7 Research Design

Research design is a blueprint of a research study consisting of four parts: what research questions to study, what data is relevant and to be collected and how to analyse the results providing a defined output of the research (Yin, 2009). Additionally, Saunders et al., (2009) describe research designs as comprising three layers building on the research onion: research strategies, methodological choices and time horizons. The relationship between Yin (2009) and Saunders et al., (2009) lies in their focus on the importance of aligning research methodology with the research questions. It highlights the aim of the research design as ensuring a cohesive connection between the research questions and the empirical data.

The research design developed for this research consists of 5 sequential stages and visually articulates the logical structure from the initial research to the conclusions, presented as objective-driven in Figure 17. The research aims to improve data quality in inventory management systems in SMEs whilst adopting a socio-technical approach. The first stage of the research involves collecting secondary data regarding inventory management systems, IMS challenges and their causal factors, critical success factors and socio-technical systems theory to understand the literature. This literature is analysed to understand the relationship between inventory management and socio-technical systems theory, underlining the importance of holistically viewing the IMS from both a technical and social perspective. This informed the development of a model of socio-technical view of IMS and a separate conceptual model, conceptualising the literature analysed. The next stage aims to validate the literature findings by collecting the primary data from inventory managers within different SMEs regarding the operation of their IMS, obtaining different perspectives and identifying challenges faced in practice. The primary data will then be used to inform the development of a framework to improve inventory data quality in IMS. The final stage of the research will test and evaluate the framework, measuring the impact of the framework on improving inventory data quality in IMS using a case study.

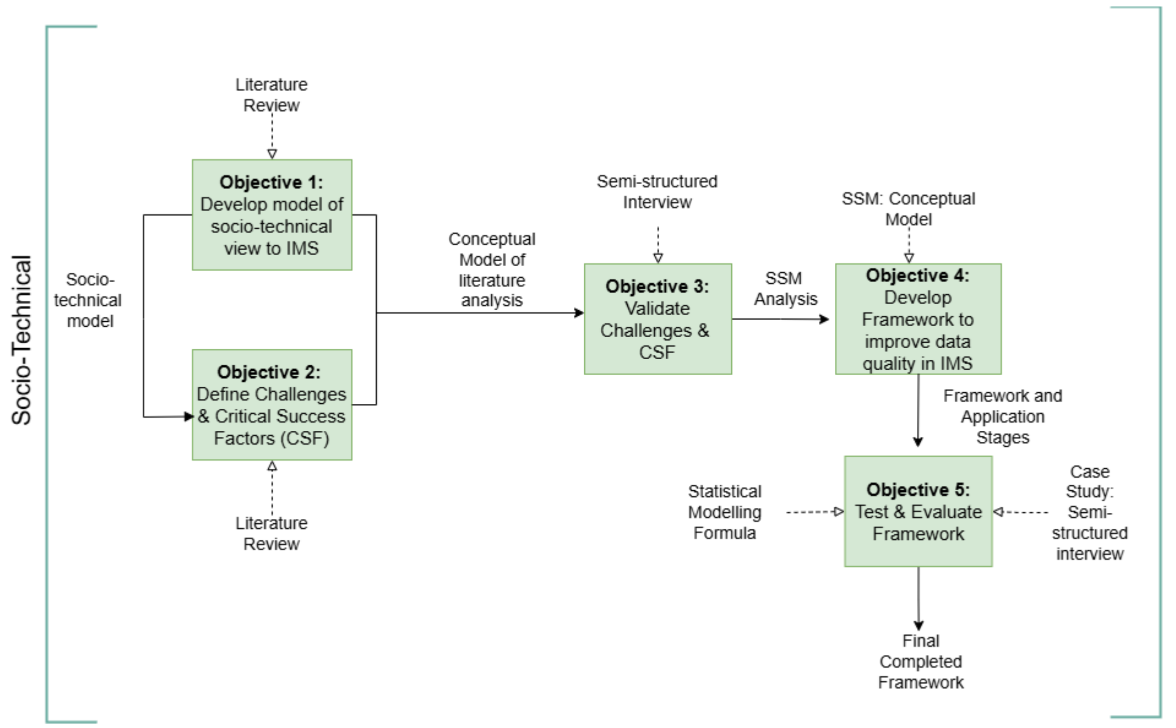

Figure 17 Research Design

3.8 Ethical Considerations

This section outlines key ethical concerns related to data integrity, confidentiality and informed consent. Adhering to ethical procedures, ethical approval was attained before conducting the primary data collection. Informed consent and access permission are important before data is collected, and this was obtained from each of the participants.

Participants were provided with a participant information sheet detailing the nature of the research and what data would be asked to provide for the research. Data was collected through semi-structured interviews from the participants and during the interviews, care was taken to maintain commercial confidentiality. The data collected was quasi-anonymised, referring to each participant as A,B,C,D,E. Sensitive data was collected relating to inventory levels, operational processes and costings. This data was anonymised during collection to protect the SME entity, where access to this data was restricted to the research and the stakeholders. Compliance with data protection regulations (GDPR) was ensured to prevent unauthorised disclosure. All collected data is stored in a secured area within the University's network up to date of graduation plus 10 years (in line with the University's Data Retention Schedule).

3.9 Chapter Summary

This chapter outlined the detailed methodology used to conduct this research study. After studying the research philosophies and paradigms, the interpretivist philosophical stance has been adopted. The selection of the qualitative research method was suitable for this study to explore the complex problem situation within IMS and its multiple perspectives, requiring in-depth data collection and analysis. Literature review and semi-structured interviews with selected as the initial data collection methods for this research. The data analysis involved using soft systems methodology to be able to explore the multiple perceptions of inventory management systems and the state of operational performance to validate the literature findings of IMS challenges, their causal factors and CSFs in the industry. Ethical considerations were also discussed and addressed to ensure that the research has been conducted abiding by ethical regulations. Overall, this chapter provides an overview of the philosophy, some methods and research design to be used to achieve the outputs of the research. The following chapter presents the primary data findings and analyses it using soft system methodology.

4 Data Collection & Analysis

4.1 Introduction

This chapter presents the results of the primary research conducted with inventory managers of five e-commerce retail SMEs in West Midlands, UK. The purpose of the primary research is to validate the literature findings in Chapter 2 regarding the IMS challenges, their causal factors and CSFs in practice, and identify additional findings from the practice of e-commerce retail. From the data collected using semi-structured interviews, soft systems methodology was used to analyse the results and requirements from the five inventory managers and design a conceptualised system to address the problematic situation. The conceptual model design underpins the thesis and establishes the need for the framework to improve data quality in IMS.

4.2 Background

IMS challenges and their causal factors have been identified from the literature in Section 2.6 and CSFs in inventory management systems have been discussed in Section 2.8. Primary data was collected through semi-structured interviews with five inventory managers from e-commerce retail SMEs in order to validate the literature findings. The semi-structured interviews consisted of both open and closed questions, as this method allows for elaboration on the open-ended questions for more depth and detailed responses (Migiro & Magangi, 2011). The semi-structured interviews enabled an in-depth understanding of the differing interpretations of IMS, the extent of the IMS challenges and causes experienced, the critical success factors implemented for effective IMS performance.

4.3 Rationale for Selection of Participants

The focus of this research targets SMEs in the West Midlands, UK, which are defined as enterprises with less than 250 employees and a turnover of less than or equal to 50 million (The European Commission, 2019). The participants selected were inventory managers within a warehouse environment. Due to the nature of inventory being non-perishable items, the scope was defined as e-commerce retail SMEs who store finished goods inventory in a warehouse environment to fulfil customer demand through online orders. A search was carried out to locate SMEs in e-commerce retail within West Midlands, UK. It targeted those with warehouses storing finished goods inventory and not operating through a physical storefront, as this research focuses on inventory management within a warehouse environment and does not consider the shop floor. Once shortlisted, SMEs were each contacted through various communication channels such as direct calling to enquire, sending emails and contacting via platforms such as LinkedIn. When contacting each SME, the range of products handled was clarified to ensure a diverse selection of SMEs were identified to participate in the research.

4.3.1 Research Participants

Table 11 Research Participants

Participant	*Description*
Participant A	A small to medium enterprise that provides authentic and branded latest and most innovative technology accessories, ranging from mobile, tablet, smart wear, smart home and PC/Laptop wear.
Participant B	A small to medium enterprise that provides an environmentally friendly and effective alternative to laundry detergent, supporting a world-friendly cause. This SME works with charity organisations to donate to shelters, communities and disaster relief groups as well as supporting the cause of cleaner oceans and planting trees to preserve the biodiversity of the earth.
Participant C	A small to medium enterprise that provides an affordable, sustainable alternative to fulfilling book demands by purchasing books that are no longer wanted, to be sold to customers in the used form to reduce waste and increase new homes for books.
Participant D	A small to medium enterprise that provides clothing merchandise for a niche market as a lifestyle brand varying from jumpers, t-shirts and clothing accessories like hats and socks, etc.
Participant E	A small to medium enterprise that provides gifts and supplies for sewing, knitting, embroidery and paper crafts etc.

Table 11 presents the selected 5 participant SMEs with a short description explaining the SME and the nature of the products. A diverse range of SMEs and product portfolio have been selected for this research, including technological accessories, laundry products and gift supplies. It is also diverse, regarding the value of the inventory items, and the speed of turnover for each SME.

4.3.2 Data Collection Scope

4.3.2.1 Design of Interview Questions

Five themes were explored when conducting the interviews with the inventory managers to find out about the challenges experienced, CSFs implemented ranking in terms of priority and importance, the existing type of IMS, technology implementation, and finally overall feedback regarding IMS performance and potential improvements.

4.3.2.1.1 Theme 1: IMS Challenges

The first set of questions related to IMS challenges and their causal factors to validate the challenges identified in literature in Section 2.6. Further explanation was requested to identify any additional challenges in practice, which led to looking at challenges in OPPT in more detail, understanding their role as factors causing the main IMS challenges to occur. This area of questioning was informed by literature in Section 2.6, for example Muchaendepi et al., (2019) suggested that inaccurate inventory data could be caused by miscommunication between people sharing information or issues with people ineffectively using technological systems, causing inaccurate inventory data. These areas were explored during the interviews. Ranking the challenges from how much they are experienced and their priority to the SME, enabled the perspective of understanding what is more important to the organisation, the impact each challenge has on the organisation, and understanding the more dominantly occurring challenges.

4.3.2.1.2 Theme 2: Critical Success Factors

The next set of questions focused on understanding which of the critical success factors are implemented, validating the CSFs identified in literature in Section 2.8. In addition, ranking the CSFs in terms of priority allows an understanding of which CSFs are more important to implement.

4.3.2.1.3 Theme 3: Type of Existing IMS

Questions were then asked about the existing type of IMS implemented if any, to relate to the types of IMS as outlined in the literature in Section 2.2. Understanding if the IMS is working well is important to define their performance, how the challenges can be impacting this and what is causing the challenges in the IMS to occur.

4.3.2.1.4 Theme 4: Technology Implemented

This theme specifically targets the use and role of technology if any implemented within the IMS. This would help validate the literature and gauge an understanding of what technology types are implemented in practice regarding inventory management in the warehouse.

4.3.2.1.5 Theme 5: Overall IMS Performance and Improvements

Finally, the last set of questions focus on the overall feedback of the IMS performance and improvements that are required to increase operational performance and reduce the instances of IMS challenges faced. Understanding the participants perspectives on how important inventory management is to the SME will help validate the literature findings that SMEs do not deem inventory management an important task and inhabit a culture of complacency ignoring key errors impacting inventory data (Kasim et al., 2015; Zomerdijik & Vries, 2003; Rekik et al., 2015). Scoping out improvements in this set of questions creates an understanding of CSFs already identified in literature and any additional ones that may be identified in practice to highlight any correlations. A detailed list of interview questions has been added to Appendix 1, including a summary of responses from each SME participant.

4.3.2.2 Semi-structured Interviews

Due to environmental circumstances of the COVID-19 outbreak, in person interviews were not possible due to social distancing regulations. Therefore, the interviews were conducted via telephone call. The interviews took place with 5 inventory managers, and by the 5th participant, it was quickly realised that the saturation point was reached, whereby the last interviewee had further strengthened the data collected from the previous participants, indicating that further data collection was not required. Saturation in data essentially means that no additional data is being found, where the researcher sees similar instances repeatedly, becoming empirically confident that the data area is now saturated (Saunders et al., 2018). Once the interviews were conducted, they needed to be analysed.

Barkat (2022) highlights some key steps in interview analysis consisting of interpreting the interview data collected:

- Report what interview was conducted.
- Document the analysis and how this was done.
- Report the findings from the interview.
- Interpret the findings.
- Justify the interpretation made.
- Synthesise the results (Barkat, 2022)

The steps have been considered in the following section.

4.4 Results and Findings: Application of SSM

This section presents the use of Soft Systems Methodology to analyse the data collected using the rich picture technique. Rich picture analysis allows a comprehensive visual demonstration of the problem situation, the understanding of multiple viewpoints, relationships, and conflicting areas, overall, allowing for deeper and richer exploration of the perspectives (Monk, 1998; Kado, 2023).

4.4.1 Stage 1 & 2- Problem Structuring

To apply stages 1 and 2 of SSM, rich pictures were prepared from the semi-structured interview data of each inventory manager to understand individual perspectives on IMS and the complex problematic situation within, validating the literature findings. The next section outlines the rich picture analysis for each SME interview. The overall consensus analysed from the interview data is presented in an individual rich picture in relation to the themes in the interview questions. Theme 1 highlights the IMS challenges and their causal factors also being experienced, theme 2 outlines the CSFs implemented, theme 3 identifies existing IMS and its performance, theme 4 identifies the technologies implemented, and theme 5 discusses the overall performance feedback and improvements.

4.4.1.1 Participant A – Rich Picture Analysis

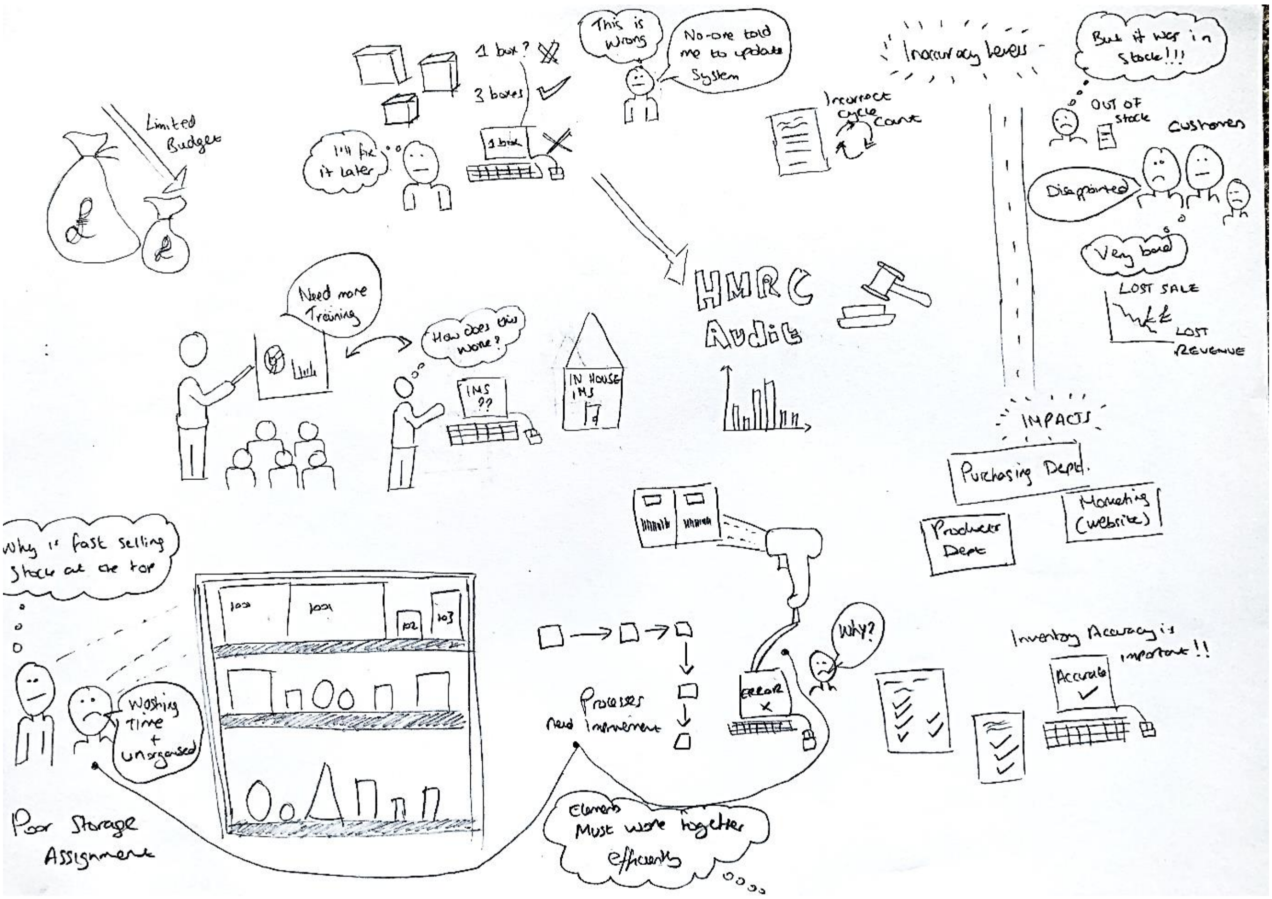

Figure 18 Participant A Rich Picture

Figure 18 in relation to theme 1 and 2, the challenges and CSFS vary from:

- A culture of complacency in the staff members in ignoring crucial inventory errors- failing to understand the importance of accurate inventory data
- Human errors in misplacing and mis-picking items disrupting the inventory level data on both a physical and system level
- Poor inventory storage organisation—storage zones are defined and try to meet all selling rates and volumes but are misallocated to products not designed for that product and purpose (too big/too small to manage the capacity of inventory). This results in wasting time locating products for fulfilment and increasing labour costs.
- Incorrect processing of inbound inventory due to not checking or counting inventory received, resulting in not adjusting inventory levels impacting sales.
- Lack of resources and budget.

- Very frequent stockouts resulting in disgruntled customers, loss in sales and poor reputation. For example, online an item will be shown as in stock, but not actually in the warehouse physically, vice versa.
- Implementing regular inventory auditing on a quarterly basis using all warehouse staff; however, counts can sometimes be incorrect, and the system is not updated with inventory movements, further disrupting the inventory level accuracy. This is important as this data must be submitted to HMRC regarding asset holding value.
- Staff training is implemented however improvements to training are required as some staff members do not understand how to use the system, follow processes and communicate effectively, creating issues in efficiency and performance of the IMS, rendering the system inadequate.

In relation to theme 3, the existing IMS implemented if any, and theme 4, the technologies implemented, the analysis identified that Participant A operates an in-house automated perpetual IMS using barcoding technology. Linking to theme 5, the overall feedback of IMS performance and improvements, the inventory manager understands that the accuracy of inventory data is critical. However, this is not reflected within the staff due to complacency. The SME is fast paced in nature of business with over 1000+ stock touches a day, and inaccuracies result in discrepancies in inventory levels leading to loss in sales and dissatisfied customers. The IMS is in place with barcoding technology, however, the overall performance needs improvement due to other problem areas such as human errors, ineffective staff communication, ignorance of inventory errors and poor quality of staff training.

4.4.1.2 Participant B – Rich Picture Analysis

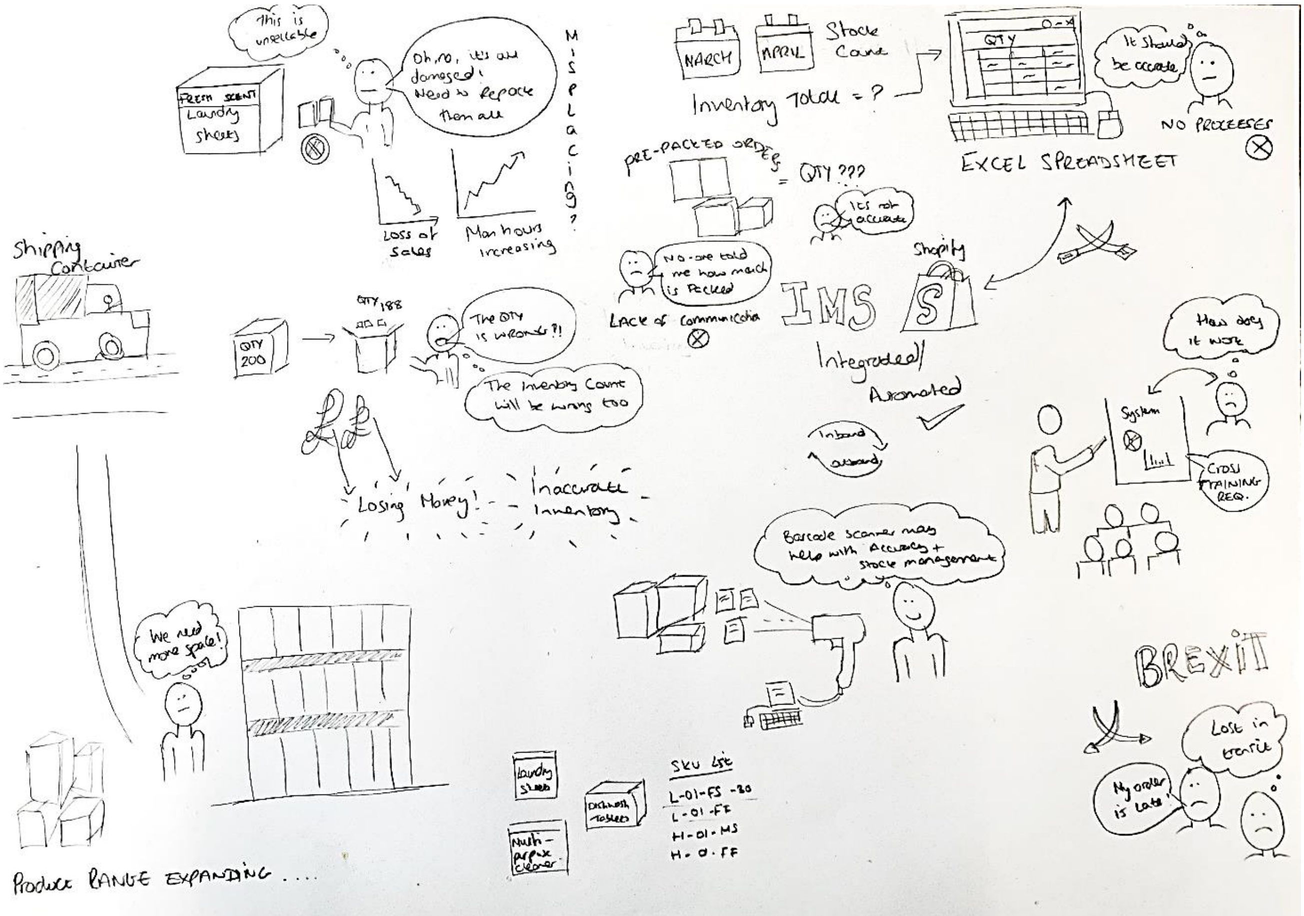

Figure 19 Participant B Rich Picture

Figure 19 in relation to theme 1, the challenges and CSFS vary from:

- Poor inventory storage - Tight warehouse space causing restriction in space when the warehouse is fully stocked, leaving limited space for staff to work in the warehouse.
- Issue in receiving and processing inbound inventory- Large deliveries in shipping container arrive with 1200 boxes at a time. Suppliers currently send incorrect amounts of inventory per box and when spot checks are done it is noticed around 10-20 units are missing in a box, causing inaccuracies in the inventory level data, and also monetary loss.
- Damaged in transit- inventory outer packaging is often damaged on arrival resulting in unsellable stock unless re-packaged which increases workload pressure on staff, increases labour and cost to the SME.
- Human error in regularly misplacing inventory

- Lack of storage design and layout of inventory as there are no zones/locations for inventory items causing discrepancies
- Frequent discrepancies in inventory level data results in in depth investigations required taking up more hours, increasing labour cost to solve discrepancies Implemented regular inventory auditing as it takes place on a monthly basis- however there are errors due to miscommunication with staff. For example, inventory would sometimes be pre-packed for fulfilment to keep up with demand, however this would always be confusing if the staff had not counted and labelled how much was pre-packed causing extra time taken to count inventory packed separately and to be sure that it is the correct inventory being counted as they are packed away. Due to lack of communication of this before the inventory count, caused blind counts to be done on the inventory that was pre-packed which are inaccurate.
- Lack of processes in place.

In relation to theme 3, the existing IMS implemented if any, and theme 4, the technologies implemented, the SME currently implement a basic Excel spreadsheet to conduct the monthly inventory counting and use an external order management system linked to the courier to process orders from the Shopify platform. Although Shopify provides an integrated IMS, it is not preferably used due to inaccuracy and causes discrepancies as inventory levels do not match both system level and physical level. The SME do not implement any technology however understand that barcoding can help to improve the accuracy of inventory in the warehouse. Linking to theme 5, the overall feedback on IMS performance and improvements, the SME requires detailed staff training due to the increased human errors of inefficiently completing tasks. Processes are required for all tasks, including receiving inventory, managing inventory for customer orders and inventory auditing. The SMEs product range is to be expanded rapidly therefore processes are urgently required for effective management of storage space in warehouse, locations and maintaining accuracy of inventory levels.

4.4.1.3 Participant C – Rich Picture Analysis

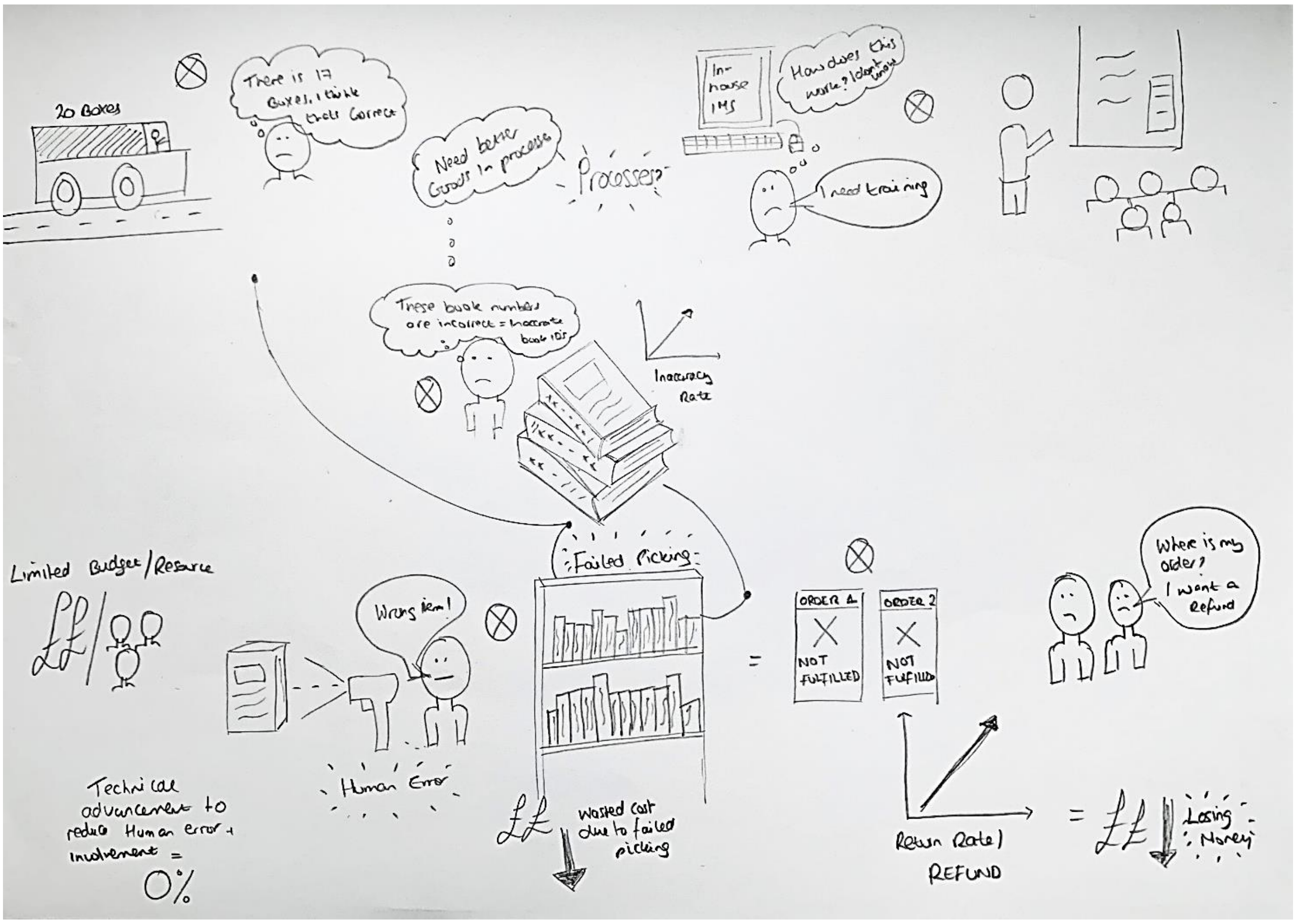

Figure 20 Participant C Rich Picture

Figure 20 in relation to theme 1 and 2, the challenges and CSFS vary from:

- Increasing rate of inaccurate inventory records due to incorrect book IDs being processed in inventory on arrival.
- Receiving inbound inventory processing is error-prone due to human error, not updating system correctly with accurate inventory levels.
- No attention to advancing technology to aid in reducing human error due to lack of budget and resources available.
- Human error in mis-picking inventory items resulting in higher labour cost and time spent locating items.
- Return rate of orders has increased showing the impact the inconsistencies are having, resulting in loss in sales and revenue.
- Lack of staff training to use the in-house system efficiently and understand the utility of the system.

In relation to theme 3 and 4, the SME implement an in-house automated IMS with barcoding technology and also outline use of a specific machine learning algorithm to replenish inventory in automatically deciding the desired quantity needed. Linking to theme 5, regarding overall performance, there are still issues resulting in accurate inventory. To improve the inventory management, a process is implemented where barcodes are being added to non-barcoded items so that this inventory can also be used with the barcoding technology to increase efficiency.

4.4.1.4 Participant D – Rich Picture Analysis

Figure 21 Participant D Rich Picture

Figure 21 in relation to theme 1 and 2, the challenges and CSFS vary from:

- SME has a limited budget and resources due to it being a very small organisation.
- Unorganised inventory storage as there are no set locations resulting in increased labour cost in time spent fulfilling order demand and managing inventory.

- Culture of complacency within the warehouse where staff would not rectify inventory level inaccuracies.
- Lack of processes and SOPS for tasks.
- No set inventory auditing policy in place.
- Human errors and miscommunications between staff.
- Increased number of returns due to incorrectly shipped products.
- Stock keeping units have been assigned to products (25 products + individual variations totalling 75 product IDs).

In relation to theme 3 and 4, the SME utilise the integration IMS provided by Shopify however there are still inaccuracies as it does not always reflect the correct inventory level. Theme 5 outlines the SMEs IMS performance as inadequate due to errors in the integrated IMS being used, inaccurate reporting of inventory levels updating. To improve the accuracy in order fulfilment and reducing mis picking products, organised inventory layout and storage is required where products are assigned to locations for easier management.

4.4.1.5 Participant E – Rich Picture Analysis

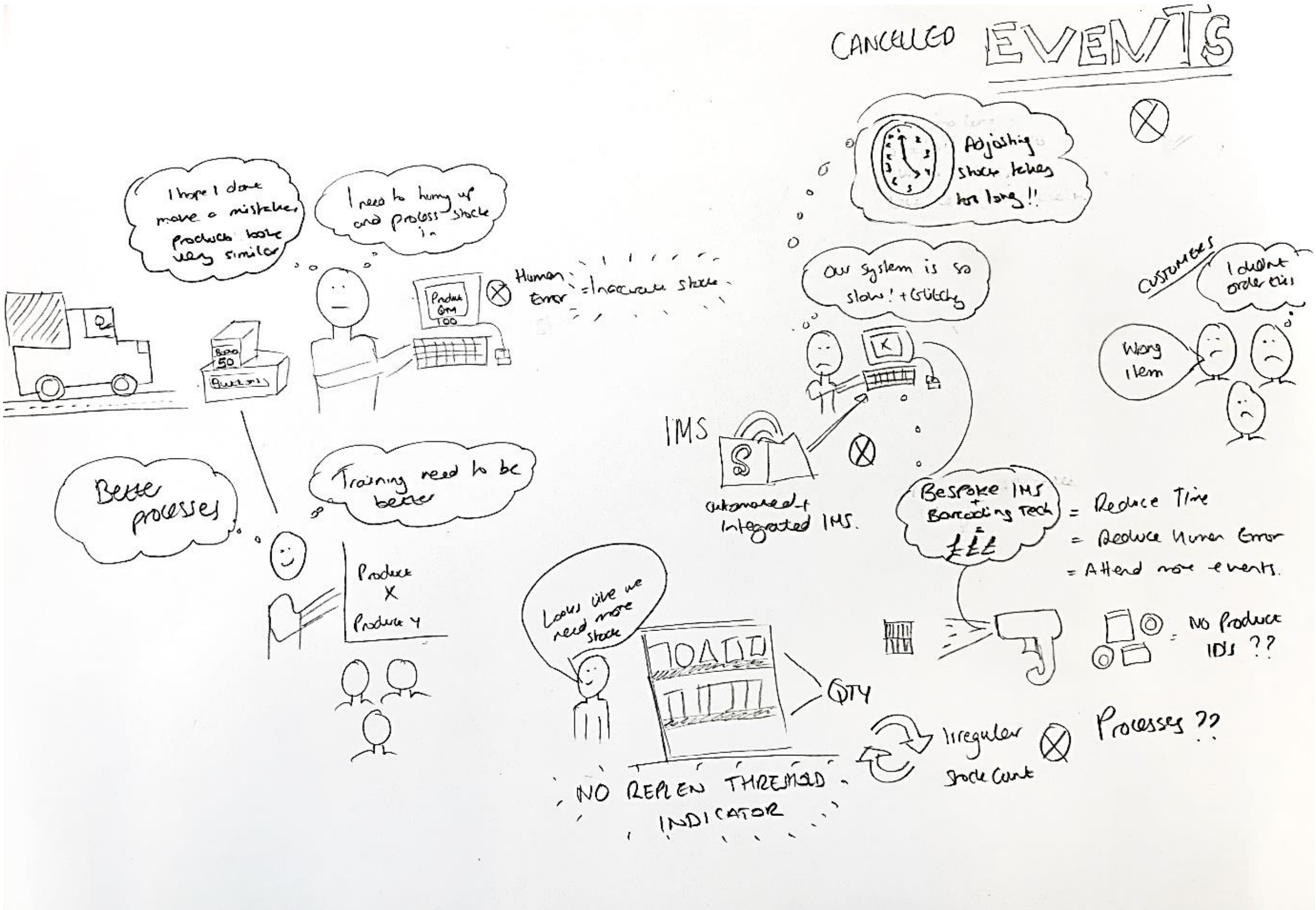

Figure 22 Participant E Rich Picture

Figure 22 in relation to theme 1 and 2, the challenges and CSFS vary from:

- Increased labour costs due to manual checks inventory levels due to system not updating and adjusting the stock levels.
- Lack of SKU assignment and only using product descriptions, leading to instances of products being inaccurately processed when received and the wrong product type entered on the stock on the system as products are close in similarity and cannot be identified quickly.
- Lack of processes.
- No inventory auditing practices in place.
- Poor quality of staff training especially using the integrated IMS system as human errors are increased.
- Events are planned, however due to inaccurate stock levels, events must be cancelled as the system shows insufficient stock is available.

- No inventory storage assignment causing delays in locating products for shipment and delay in orders.
- Increase in returned orders due to incorrect product sent resulting in disgruntled customers.
- Lack of replenishment indicator to know when inventory is running low for particular products and need to be replenished resulting in missed customer orders.

In terms of theme 3 and 4, the SME implements the integrated IMS system provided by Shopify however there are some issues as there are delays in adjusting the stock levels, causing inaccurate inventory level data in real time. Relating to theme 5, the SME recognises that barcoding technology can with a bespoke IMS can help to reduce the time wasted and labour cost due to manual checks of inventory levels, reduce instances of human errors and help to maintain accurate inventory levels updated in real time.

The perspectives from all individual rich pictures were put together, resulting in a combined, collective view of the data collected to form one complete rich picture from the interview data. This was due to the emergence of repetition amongst the participants. Combining the rich pictures into one final one aligns with the interpretivism philosophy, ensuring that all stakeholder perspectives are synthesised, and the problem situation is structured.

4.4.1.6 Combined Rich Picture

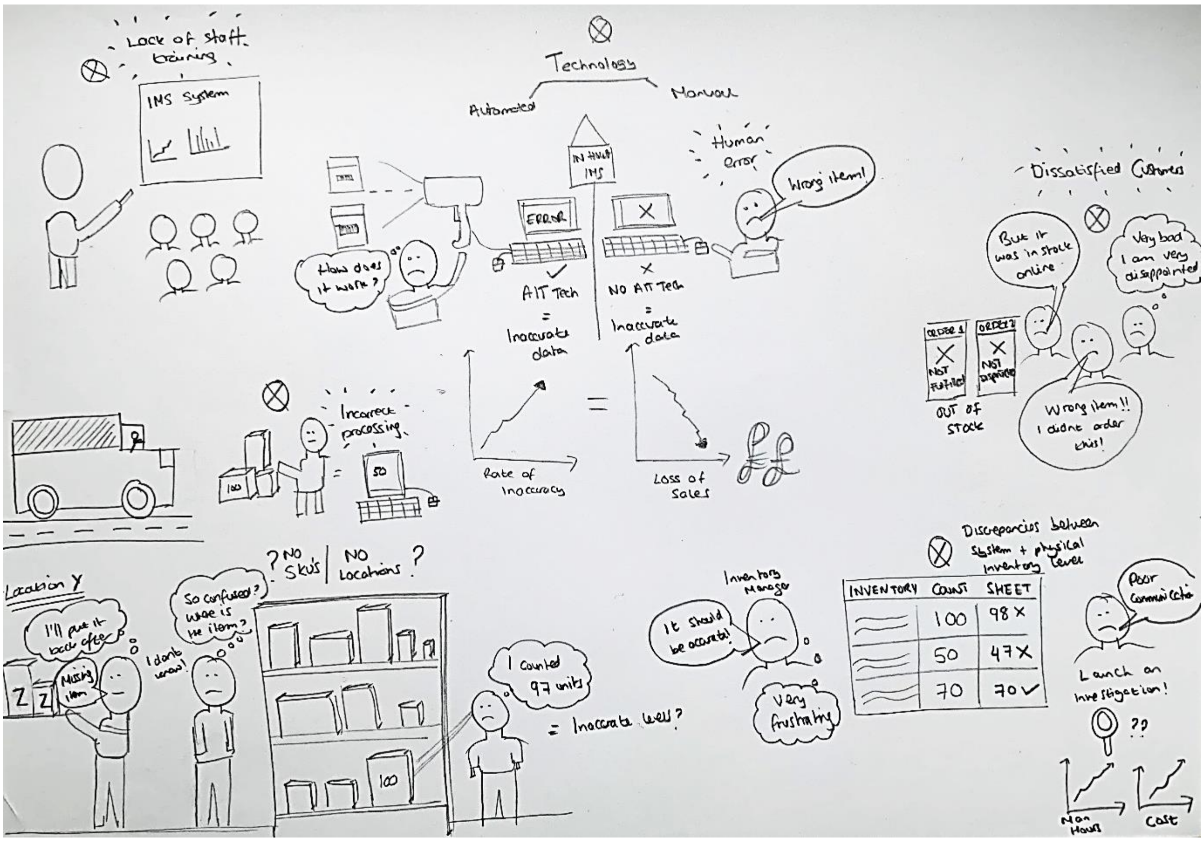

Figure 23 Combined Rich Picture

Figure 23 presents the combined rich picture, showing a collective understanding of the state of the IMS and problematic situations across the 5 SMEs. A combined rich picture was developed due to repetition emerging amongst the data being collected from each of the participants. Merging the rich pictures ensures that all relevant insights are captured without the necessary duplication. Checkland (1999) emphasises that rich pictures evolve as a shared understanding, therefore if multiple rich pictures reflect the same issues, merging into a combined rich picture improves clarity of the problematic situation. The next stage explains the application of the CATWOE tool to develop the root definition using the worldview from the combined rich picture.

4.4.2 Stage 3- Develop Root Definition

4.4.2.1 CATWOE Analysis

Following the analysis of the data gathered from five SME inventory managers regarding their IMS through rich pictures, the next stage is to develop the root definition of the relevant purposeful notional system required using the CATWOE tool. The CATWOE analysis and root definition were based on the combined rich picture to extract the main worldview and a transformation process.

Table 12 CATWOE Analysis

C	Customer	Small to medium enterprises (SMEs)
A	Actors	Consultant
T	Transformation Process	A need to improve the accuracy of inventory data
W	Worldview	Quality of inventory data determines the effectiveness of the inventory management system
O	Owners	Inventory managers, CEOs
E	Environmental Constraints	Must be suitable for SME organisations at different stages in their IMS Must integrate into existing systems Interoperability of the socio-technical elements Data must be timely and accessible to be accurate data

Table 12 presents the CATWOE analysis for the combined worldview, showing that the quality of inventory data determines the effectiveness of the IMS. As a result, a transformation process was developed in the CATWOE as *'A need to improve the accuracy of inventory data'*. The next step is to develop the root definition of the established worldview. The established root definition combines the CATWOE and is represented as the perceived system, to improve the problematic situation outlined in the rich pictures.

4.4.2.2 Root Definition

Table 13 Developed Root Definition

Root Definition
A system owned by inventory managers/CEOs, operated by a consultant to improve the accuracy of inventory data for the benefit of small to medium enterprises (SMEs),

in order to address the different factors affecting inventory data quality, as the quality of inventory data determines the effectiveness of the inventory management system, within the constraints of ensuring it is suitable for SME organisations at different stages in their inventory management, must integrate into existing systems, recognise the need for interoperability of the socio-technical elements: people, process and technology and ensuring that the inventory data is timely and accessible for accuracy.

The final combined rich picture was used to develop a single CATWOE and single root definition to avoid further repetition, as it would not have provided any new insights separately. Instead, it has provided a detailed CATWOE and root definition based on the combined worldview and identified an actionable transformation process to improve IMS. A single CATWOE helps to define the worldview in a unified way, ensuring stakeholder roles are clearly structured as Winter & Checkland (2003) explain that CATWOE can be used to analyse a single, well-defined system rather than being repeated across similar cases. As the final combined rich picture and single CATWOE already combine the worldviews from SMEs, having multiple root definitions would consist of similar descriptions of the system purpose and inconsistencies in defining the system's boundary, resulting in difficulty in deriving actionable insights required in the conceptual model.

4.4.3 Stage 4: Develop Conceptual Model

4.4.3.1 Conceptual Model

Stage 4 of SSM was applied and a conceptual model was developed using the identified transformation process from the CATWOE and root definition. The conceptual model represents the activities and their arrangement necessary to undertake the transformation process. An activity within the conceptual model includes a minimum of one input and output. The transformation process depicted as a system in the conceptual model is to: ***'Improve the accuracy of inventory data'***

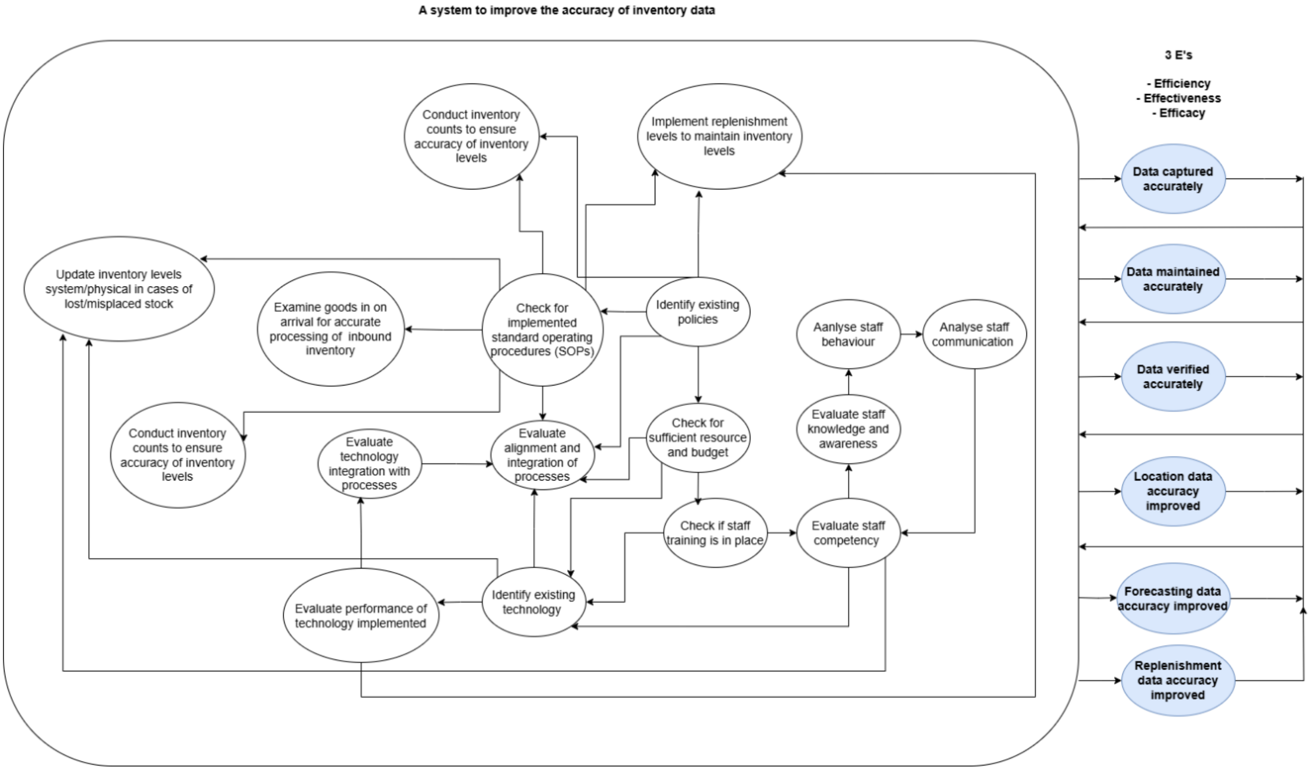

Figure 24 Conceptual Model to Improve the Accuracy of Inventory Data

Figure 24 depicts the conceptual model, showing the activities required to satisfy the transformation process outlined in the CATWOE: '*to improve the accuracy of inventory data'*. The activities with outputs from the system boundary are presented as the 3 e's being efficiency, effectiveness and efficacy, to test the transformation process in the model. To improve the accuracy of inventory data, it needs to be captured accurately, maintained accurately, and verified accurately. Efficacy tests whether the intended transformation is taking place and improving as expected. This is tested by checking whether the inventory data accuracy has improved. This can be determined by measuring the error rate of how many stock entries contain errors during periodic inventory audits to compare physical inventory levels with system levels. Efficiency assesses whether the transformation process is optimised in terms of cost and occurs with minimal resource use. This is tested by answering whether inventory accuracy improvements are being made without excessive costs or delay. To test this, the time taken to update inventory levels can be measured. Effectiveness determines whether the transformation process contributes to the wider goal and delivery of meaningful business value. This is tested by answering if the accuracy improvements are translating into better inventory management, cost savings and stock availability. To test this, the number of stockouts or overstock issues can be measured, the average time to locate an item can be measured for reduction and verify if replenishment data accuracy has resulted in better inventory replenishment avoiding stock-outs. For example, check that processes are in place, adequate staff training is in place, technology, if implemented, is working as expected and is integrated well. All activities outlined in the conceptual model contribute to achieving the key transformation process.

4.5 Chapter Summary

This chapter documents the data collection, findings and analysis from the SME participants to validate the literature findings in Chapter 2. Soft systems analysis has been applied enabling the development of rich pictures to analyse the problem situations within the SME organisations and understand the multiple perceptions of inventory management systems. All the IMS challenges and causal factors from the literature in Section 2.6, were reported by the SMEs, with inventory inaccuracy being the most prominent challenge experienced. All the CSFs identified from the literature in Section 2.8 were reported by SMEs. From the semi-structured interview data collection and the rich picture analysis conducted for each SME, it is noted that there is increased similarity and agreement between the literature findings and IMS challenges and their causal factors experienced. Some of the challenges consistent across the SMEs are human error, inaccurate inventory levels, lack of processes or error-prone processes, little or no staff training, miscommunication amongst staff, culture of complacency, limited budget and resource, poor storage of inventory and space planning in the warehouse. The final combined rich picture then enabled a CATWOE analysis being completed followed by a root definition outlining the key transformation process ***'Improve the accuracy of inventory data'*** required to develop the conceptual model. The conceptual model details the activities needed to implement the transformation process. This conceptual model then provided the foundation of designing and developing the framework, as presented in the next chapter.

5 Design and Development of the Framework

5.1 Introduction

The conceptual model developed in the previous chapter to address the transformation process ‘to improve the accuracy of inventory data’ laid the foundation for the design and development of the framework which is presented in this chapter. The framework is the implementation of the conceptual model and aims to improve inventory data quality in SMEs. In the first part of this chapter the design of the framework is outlined, leading to the development of the framework into 3 stages: i) Development of the Inventory Management Context Capture Tool (IMCCT), ii) Development of the Inventory System Maturity Model (IMSMM) and iii) Development of Stating and Recommending Improvement Actions.

5.2 Design of the Framework

The previous chapter finalised the development of a conceptual model presenting a notional system to conduct the key transformation process identified *‘to improve the accuracy of inventory data’* in Section 4.4.3.1 in Figure 24. Three core areas were identified from the conceptual model, which resulted in the activities being divided and grouped. This is presented in Figure 25.

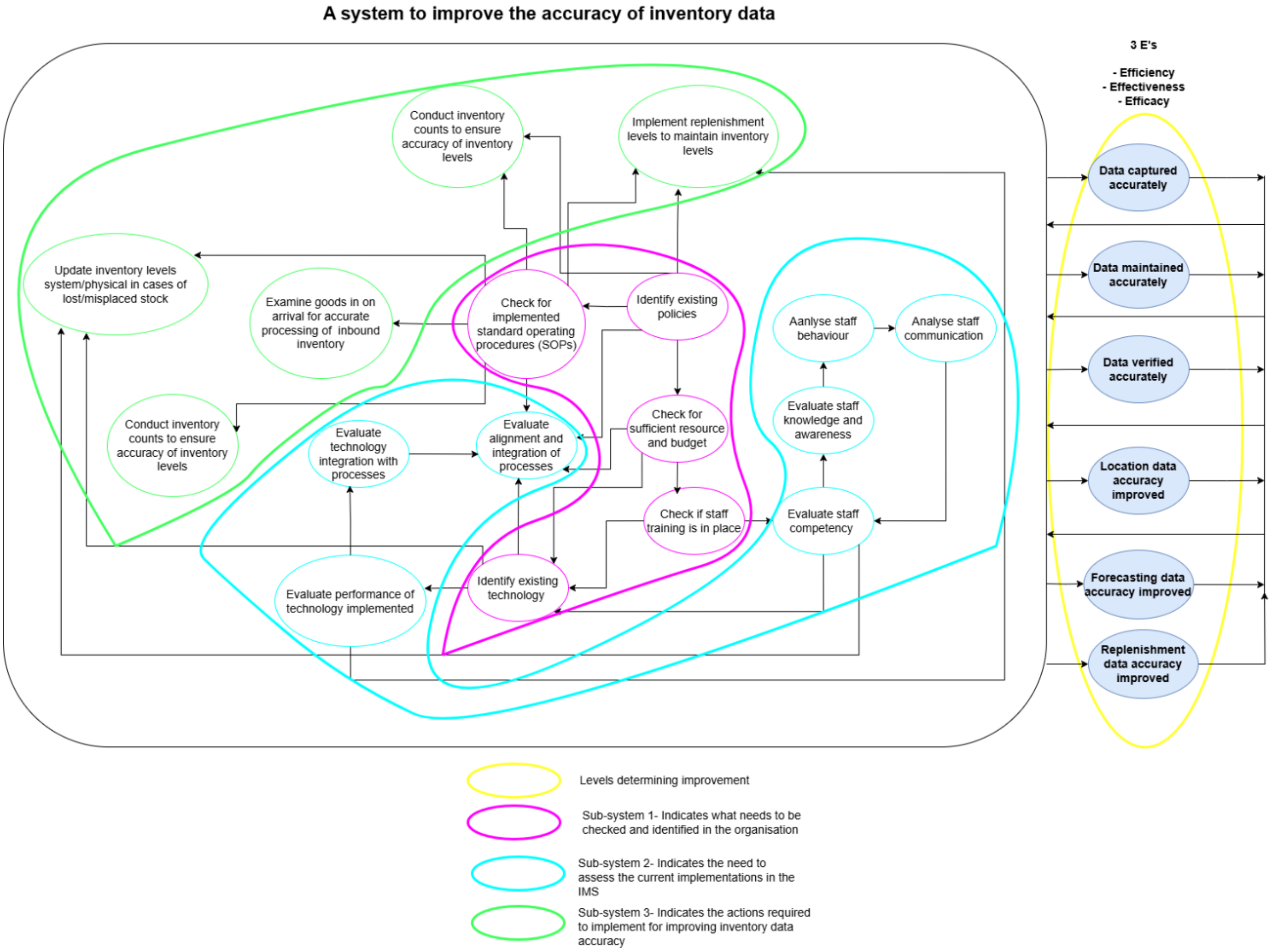

Figure 25 Core Areas Within the Conceptual Model

Figure 25 presents the coloured key regarding the identified 3 sub-systems. Sub-system 1 consists of the following activities: check for implemented standard operating procedures (SOPs), identify existing processes, check for sufficient resource and budget, check if staff training is in place and identify existing technology. This sub-system highlights what needs to be checked and identified in the organisation, indicating that an understanding of the SME and their IMS is required before implementing any actionable improvements. Sub-system 2 consists of the following activities: analyse staff behaviour, analyse staff communication, evaluate staff knowledge and awareness, evaluate staff competency, evaluate alignment and integration of processes, evaluate technology integration with processes and evaluate performance of technology implemented. This sub-system indicates the need to assess the current implementations in their IMS of processes, technology and the staff's attitudes and behaviours. Sub-system 3 consists of the following activities: conduct inventory counts to ensure accuracy of inventory levels, implement replenishment levels to maintain inventory levels, update inventory levels system/physical in cases of lost/misplaced inventory and examine goods in on arrival for accurate processing of inbound inventory. This third sub-system indicates the actions required to implement based on the previous information gathered for improvement, to meet the transformation process to improve the accuracy of inventory data. The conceptual model works to meet the transformation process, which is ultimately the improvement in the inventory data accuracy. This recognises that the transformation process indicates improvement from a current state to an improved state. This is supported by the sub-system one activities enabling the understanding of the current state in the IMS, sub-system 2 assessing the existing implementations in the IMS and sub-system 3 identifying actionable improvements combined to meet the overall transformation process improvement. The conceptual model can be implemented through the development of a framework informed by the activities in the conceptual model. Therefore, the grouped activities in sub-system 1 will form stage 1 of the framework, the grouped activities in sub-system 2 will form stage 2 of the framework, and the grouped activities in sub-system 3 will form stage 3 of the framework.

Stage 1 identifies the current state of the IMS in the SME, stage 2 assesses the current performance of the IMS and finally stage 3 identifies the improvement actions required to improve the IMS from current state to an improved state. This led to the understanding that a maturity model will be required to 'mature' the current state of the IMS to an improved state in terms of the inventory data quality. The next section outlines the development of stage 1 of the framework.

5.3 Development of the 3-Stage Framework

Figure 25 provides the foundation for a three-stage framework to be developed to improve inventory data quality and this section documents the design of each of the stages.

5.3.1 Stage 1: Development of The Inventory Management Context Capture Tool (IMCCT)

Stage 1 of the 3-stage framework is the Inventory Management Context Capture Tool (IMCCT), developed to capture the context and overview of the IMS within the SME. The IMCCT was developed as a natural extension of the primary research conducted and the conceptual model activities in sub-system 1, recognising the need for additional data in order to fully comprehend the context of the inventory management system and to further identify specific challenges within the IMS. The IMCCT serves the purpose of obtaining the current situational context of an SME organisation facilitating collection of data, enhancing both clarity and insight. Moreover, the IMCCT assists in identifying different characteristics of an organisation, unveiling similarities and differences that affect its ability to manage inventory effectively. This then in turn, provides essential context for the maturity assessment to be conducted in stage 2.

Figure 26 shows the data required in the IMCCT to split into 3 main tiles: Organisation Details, Inventory Overview, and Organisational Overview. Attached to the IMCCT is a set of supporting documentation in the format of a table containing all additional information to be collected per tile, as shown in Table 14. Firstly, it is important to understand the organisation and its nature as presented in the organisation details section. Secondly, as part of the IMCCT, it is important to obtain an overview of the inventory situation, covering type of inventory, storage information, product range/variations and stock keeping unit assignment. Finally, the third section of the IMCCT details the organisational overview in specific relation to the management of inventory such as: workflows, stakeholders, process documentation, warehouse layout, technologies implemented, training and occurrences of IMS challenges. The information in Table 14 was derived from the literature findings, semi-structured interviews and also an understanding as to what information is required to obtain an overview of the organisation to capture its IMS context.

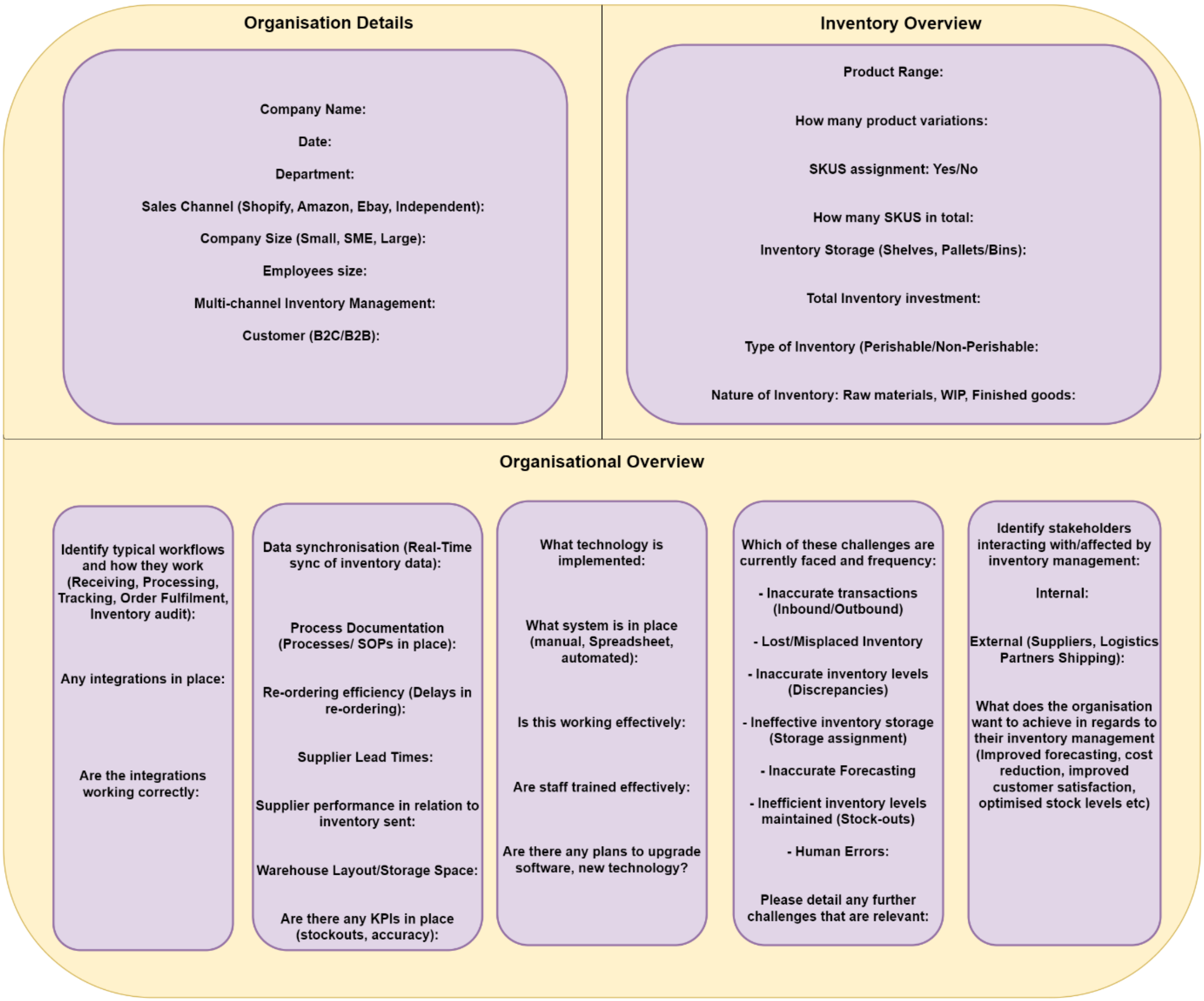

Figure 26 Inventory Management Context Capture Tool (IMCCT)

Table 14 Supporting Documentation to be completed alongside Inventory Management Context Capture Tool (IMCCT)

Organisational Details	**Company Name**	
	Date	
	Department	
	Sales Channel	
	Company Size	
	Employees	
	Multi-channel Inventory Management	
	Customer	
Inventory Overview	**Product Range**	
	Product Variations	
	SKUS Assignment	
	SKUS Quantity	
	Inventory Storage	
	Total Inventory Holding Investment	
	Type of Inventory	
	Nature of Inventory	

Organisational Overview	**Identify Workflows**	
	Integrations In Place	
	Integrations performance (working correctly)	
	Issues with Systems	
	Staff Trained Effectively	
	Challenges Faced	
	Data Synchronisation (Real Time sync)	
	Processes/SOPS	
	Frequency of Inbound Inventory	
	Replenishment Threshold	
	Supplier Lead Times	
	Supplier Performance	
	Warehouse Layout/Storage Space:	
	KPIs in place:	
	Any plans to upgrade software/Technology:	
	Expected achievements in terms of inventory management:	
	Identify Stakeholders:	

5.3.2 Stage 2: Development of The Inventory Management System Maturity Model (IMSMM)

This section outlines the relevant maturity model literature to further explore the adoption of maturity models to improve an SME organisation from current state to an improved state in their inventory data quality. The section first provides an overview of maturity models, types of maturity models and examples of existing maturity models. Existing maturity models used in logistics/warehousing domain are evaluated and methodologies for developing maturity models are reviewed. The section then selects De Bruin et al., (2005) methodology to detail the development of the IMSMM as part of stage 2 in this framework.

5.3.2.1 Overview of Maturity Models & Purpose

Maturity implies "evolutionary progress" in improving a skill or achieving a goal. It begins with an initial state where there is a low output performance and progresses to a final state where optimum maturity is reached (Garcia-Mereles, 2012). Becker et al., (2010) define maturity "as a measure to evaluate the capabilities of an organisation with regards to a certain discipline". Maturity models are a defined set of sequential levels, usually following a logical staged growth path from an initial state to a more improved final state (Proença, 2016; Monteiro & Maciel, 2020). Monteiro & Maciel (2020) state that maturity models are composed of maturity levels, summary of characteristics, indicators of what the organisation needs to focus on at each level and finally a specific method to assess and determine the current maturity position. Maturity models are designed as assessment and improvement tools used to assess the as-is situation within an organisation and offer improvement measures to attain optimal competency within a discipline (Becker et al., 2010; Adekunle et al., 2022). Achieving a higher level of maturity overall results in better control of the outcome, accurate forecasting of goals and performance and overall higher effectiveness in reaching the goals set for optimal performance (De Oliveira, 2011).

Razik et al., (2017) states that maturity models aim to address the need for process improvement. Maturity models enable businesses to carry out a self-assessment to improve their level of performance by adhering to and developing their maturity levels in the intended area. Maturity models are useful in evaluating an organisation's strengths and weaknesses to carry them to the next level of maturity for set goals to be achieved (Razik et al., 2017). The main purpose of maturity models is to outline a path to maturation through its stages and provide a framework for organisations to improve their business performance. This can be done by assessing strengths and weaknesses and measuring the success when improvements are stabilised, as well as assess how skilled an organisation is and its current maturity (Gomes et al., 2013; Lasrado et al, 2015; Monteiro & Maciel, 2020).

Gomes et al., (2013) explain that maturity models allow organisations to plan how to reach higher maturity levels by integrating organisational functions, setting process improvement targets and goals and providing benchmarks for the set outcomes to be achieved. In addition, Gomes et al., (2013) explain how investment success lies with process improvement, changes in organisational performance, and modifications to business processes. Traditionally, organisational improvement and development consider the technical and economic aspects, however the social aspect is also crucial as the social (people) factors are key to recognising essential parts of work systems (Hughes et al., 2017). Among many other tools used for process improvement, the maturity model is widely used as organisations will rely on improving internal processes to improve the probability of success (Razik et al., 2017). De Bruin et al., (2005) state that validation of maturity models is important to ensure relevance for practice.

Table 15 Characteristics and Definitions When Developing Maturity Models (Based on: Lasrado et al., (2015) and Monteiro & Maciel, 2020))

Maturity Levels	**Same as stages, levels, maturity score. This is used to describe the maturity status of the target entity and the level best placed at for performance.**
Dimensions	Also known as reference variables, process areas, capacity and critical success factors.
Subcategories	2nd level variables that the dimensions are dependent on.
Path to Maturity	Most models tend to follow a linear path of lesser to greatest maturity.
Evaluation Issues	This is linked to the subcategories such as the maturity level or score given and is usually shown in a graphical representation.

Table 15 presents a generic structure of a maturity model shown in two parts, the first being the general design structure of the model comprising of the stages, dimensions, and sub-categories and the second part shows the relationships between the components of the model outlining the path to maturity and its evaluation. It is necessary to empirically demonstrate growth patterns and development through the stages/levels so that evaluation and validation of maturity models can take place (Solli-Saether & Gottschalk, 2010). In addition, it can be argued that organisational growth does not have to necessarily show progress through the linear sequence of stages but can be shown through identifying problems, and the strategies and processes in place to determine progress (Solli-Saether & Gottschalk, 2010). The next section outlines maturity levels in more detail.

5.3.2.2 Maturity levels

Maturity levels are used to assess a certain readiness in an area of performance, and it is important that these levels are selected coherently either in a qualitative or quantitative way (Ruile & Lichtsteiner, 2022). Maturity levels proposed can vary, for example, negligible, low, moderate and high. Each level consists of a measure for example, a negligible maturity level might correlate with sub 25% usage of a certain measurement (specified separately). A high maturity level might correlate to a 75%-100% usage measurement (Ruile & Lichtsteiner, 2022). Maturity levels can vary based on the context of the maturity model for example, Ruile & Lichtsteiner (2022), specify the levels for a technology progression model as manual, mechanised, automated, digitally augmented and lastly intelligently dark. The final intelligent dark maturity level would mean that all the work, processes and services are done in an autonomous way including the use of robotics. Another example based on a maturity model to automate data transfer, specifies the levels of data digitalisation as, paper transfer of data, digital transfer of data, use of ERP systems to automate data transfer (Ruile & Lichtsteiner, 2022).

Table 16 Generic Maturity Level Descriptions (Sourced from: Ruile & Lichtsteiner, 2022)

Maturity Level	*Description*
Ignoring	No awareness regarding needs for integration of any advanced technology into operations. Missing knowledge about the benefits of such solutions for enhancements
Defining	Need for integration is acknowledged with knowledge of the advanced solutions, but missing knowledge of implementation and application
Adopting	Basic steps for integration of the advanced technology initiated with some implementations of advanced solutions
Managing	The integration is driven forwards and most of the advanced solutions available are implemented to enhance operations
Integrated	Top level integration achieved, full potential synergies and all advanced solutions are implemented resulting in optimised flow of goods/information

Ruile & Lichtsteiner (2022) propose generic maturity levels as shown in Table 16. Maturity levels represent a degree of maturity in their respective dimension and every level needs a general description which can then allow for improvements to be offered in that specific area at each level. As explained by De Bruin et al., (2005) it is important to have well defined maturity levels where it is clear to see the logical progression from one to another. The measurements of levels can be carried out using Guttman scales or Likert scales. Guttman is a cumulative scaling technique which suggests a linear relationship based on ordering (Solli-Saether & Gottschalk, 2010). A five-point 'Likert' scale is the most widely used scale in survey research for evaluating maturity with 1 being the lowest level of maturity and 5 being the highest level of maturity (De Bruin et al., 2005; Solli-Saether & Gottschalk, 2010). Maturity levels are cumulative, meaning that a level needs to be achieved before systematically going to the next making it stratified (Adekunle et al., 2022).

5.3.2.3 Classification of Maturity Models

Lasrado et al., (2015) and Monteiro & Maciel (2020) have classified maturity models depending on the construction of the dimensions, stages and levels:

- Conceptual maturity models: These models use a theoretical approach when deriving dimensions. A strong theoretical underpinning and foundation is necessary.
- Qualitative/ Quantitative maturity models: The models use an empirical approach to derive the dimensions and stage/levels. A literature review is usually followed up by a conceptual maturity model.
- Practical maturity models: The models are developed specifically keeping a practitioner perspective in mind, can be quite comprehensive and are not usually targeted to academia.
- Derivative maturity models: The models mostly use prior published literature on maturity models to fit relevant domain problems into the structure without having strong theoretical or empirical foundations mentioned.

Monteiro & Maciel's (2020) study findings were that out of 13 maturity models, most of the models analysed were predominantly conceptual when it came to deriving dimensions and maturity levels.

5.3.2.4 Types of Maturity Models

There are three main types that maturity models are placed in for practical application, which are a descriptive model, prescriptive model, and a comparative model.

- Descriptive: A descriptive model serves as a diagnostic tool used as a single point of assessment of the as-is situation. It assesses current capabilities and does not recommend improvements to maturity. Once a maturity score has been assigned, it can then be reported to the stakeholders involved (De Bruin et al, 2005; Poppelbub & Roglinger, 2011).
- Prescriptive: A prescriptive model focuses on the relationships to performance and indicates maturity improvement measures and guidance to increase

business value, prescribing a roadmap of improvement (De Bruin et al, 2005; Poppelbub & Roglinger, 2011).

- Comparative: A comparative model enables either internal or external benchmarking across industries/organisations, where a comparison of practices is done across these organisations to benchmark a maturity level (De Bruin et al., 2005; Poppelbub & Roglinger, 2011).

5.3.2.5 Examples of Existing Maturity Models

The following section discusses the existing maturity models identified from literature: capability maturity model, organisational project management maturity model, project management maturity model and Nolan's stages of growth maturity model.

5.3.2.5.1 Capability Maturity Model (CMM)

Maturity models as an idea derived originally from the software engineering industry in 1993 at Carnegie Mellon University, Pittsburgh USA where the first Capability Maturity Model (CMM) was developed. The CMM is a standard process which assesses the level of quality of IT organisations through analysing their performance levels of the software development process (Battista & Schiraldi, 2013). The CMM model is a process improvement model that has formed the foundation of subsequent maturity models, deriving from this first concept (Ghaffari, 2018). Razik et al., (2017) explains that the concept of process maturity was used for the first time in Total Quality Management (TQM) and then broadly featured and used in CMM in software organisations. The concept of process maturity was then adopted for organisational process and project management maturity models. In addition, Battista & Schiraldi (2013) also states that the CMM develops standardized processes so that quality levels can be assessed in the information technology area within organisations and their software development processes. In agreement, Gomes et al., (2013) identify two other popularly referenced maturity models which are OPM3 and P3M3 as explained in the following section.

5.3.2.5.2 Organisational Project Management Maturity Model (OPM3) & Project Management Maturity Model (P3MP)

Organisational project management maturity model OPM3, as explained by Gomes et al., (2013) is a process model for executing single projects. The model measures the maturity of a project as a percentage of best practices achieved. This is classed as a type of descriptive model. The P3MP is an enhanced version of the OPM3 where it provides a framework for an organisation to assess its current performance and then initiate improvement plans. This is an example of a prescriptive model.

5.3.2.5.3 Nolan Stages of Growth Maturity Model

Nolan's (1979) Stages of growth model (NSGT) was the first maturity model in computing offering a theoretical framework to the development of Management Information Systems (MIS) for the assimilation of IT in organisations (Favaretto & Meirelles, 2015). In his first version of the Stage of Growth Model (SGM) presented in 1973, Nolan suggested a descriptive model where the planning, organization and control of organizational activities associated with the assimilation of computer technologies (now ICT/IS initiatives), would change over a period of time. The SGM consists of 4 stages: initiation, contagion, control and integration. Nolan developed a later version in 1975, consisting of 6 stages adding data administration and maturity as additional stages in SGM. Nolan looks at how organisations are developing and what problems they are having at each stage, with the focus being growth of IT in an organisation (Favaretto & Meirelles, 2015). It is seen that Nolan was the first researcher to introduce a structured scheme in this way to explain the growth of computing technology in organisations (Favaretto & Meirelles, 2015).

5.3.2.6 Existing Maturity Models within Logistics Domain

There are many different pieces of work in different industrial sectors which have shown the benefits of using maturity models and the relationship between improving maturity and performance overall (Razik et al., 2017). This section explores the existing maturity models within the logistics domain with two spanning the warehousing system. The models explored are, the supply chain process management maturity model, logistics maturity model, warehousing function maturity model, autonomous warehouse model and the logistics maturity model for a service enterprise.

5.3.2.6.1 The Supply Chain Process Management Maturity Model (SCPM3)

Supply Chain model (SCPM3) is the first process maturity model that uses statistical analysis to aid in defining maturity levels and the best practices in place at each level. This presents the SCPM3 as a benchmarking-type maturity model. This model works in the way where an organisation would need to complete an assessment using the indicators given and use this score to assess their current maturity. This helps the development of an action plan to improve process maturity using the best practices correlating to each relevant level to increase progression to the next levels (De Oliveira, 2011).

5.3.2.6.2 Logistics Maturity Model (LMM) (Battista & Schiraldi, 2013)

Battista & Schiraldi (2013) present a Logistic Maturity Model (LMM) that has been created for the logistics environment. The logistics maturity model indicates the potential improvements to the performance of logistics processes that can be achieved by identifying best within industry. The model consists of 5 levels of maturity, key performance indicators and best practices to allow for process maturity. The LMM focuses on 4 large logistics areas which incorporate several sub-processes, such as demand planning, procurement, inventory control, warehousing, material handling and shipment planning.

The five levels of maturity are as below:

Level 1: a business need is acknowledged but the related process is not managed.

Level 2: the process is managed but it is neither formalized nor standardized.

Level 3: the process is formalized and standardized, but it is neither controlled nor monitored.

Level 4: the process is controlled and monitored but it is not optimized.

Level 5: the process is optimized.

The maturity is calculated for each logistic area based on achievement indicators and processes and sub-processes. Specific best practices are then defined to improve maturity. The LMM was tested within a fashion retailer, which allowed the maturity profile to be measured, identifying the weak points in the logistics processes and developing a process improvement map with the transformation of operative actions, identifying which best practices should be adopted. Each maturity level is related to achievement indicators, and increasing maturity to move up levels is measured by the percentage of accomplished achievements, resulting in the assigned maturity score.

Overall, the LMM application was summarised in three steps, firstly maturity assessment, secondly weak point identification and thirdly improvement of the roadmap definition (Battista & Schiraldi, 2013).

5.3.2.6.3 Warehousing Function Maturity Model (Razik et al., 2017)

Razik et al., (2017) found that there was a lack of research in maturity models for warehouses, and developed a maturity model for the warehousing function. Initially, the warehouse functions are outlined, warehouse performance indicators are identified, and a list of critical success factors for improving warehousing performance is presented. In the maturity model, three maturity levels are presented. Level one is that there are no processes and is chaotic, level two is where warehousing function processes are documented, standardised and integrated into standard implementation process. Level three is where warehousing function process and activities are controlled and managed based on quantitative models and tools. The four main components of the warehousing function are, warehouse design, warehouse resources, warehouse operations, and warehouse management. For each warehouse function there is a corresponding list of CSF and attached to each CSF is level 1, 2 or 3 depending on the implementation level of that CSF, overall showing how CSF can be used for improving maturity in an area/dimension within this model.

5.3.2.6.4 Autonomous Warehousing model (Ruile & Lichtsteiner, 2022)

Ruile & Lichtsteiner (2022) present a maturity model using a holistic socio-technical approach to the digital transformation of warehousing into autonomous warehousing. The model targets all warehouse activities for their assessment with concepts, such as process-oriented approach, people concepts, technology adoption and implementation as well as organisational aspects. To develop their model, Ruile & Lichtsteiner (2022) applied the methodology of De Bruin et al., (2005) six phase approach, as well as considering relevant literature and industry interviews to validate and ensure the rigour of their maturity model. They used a single case study to deploy and test the maturity model. In their model, there are 5 maturity levels in two dimensions with categories resulting in a total of 32 elements. Their model shows an intersection across the warehousing processes, the maturity levels, and integrating the socio-technical viewpoint. This model is more dynamic in nature, encompassing a working hypothesis of maturity, which is seen beyond linear processes. Ruile & Lichtsteiner (2022) have recognised the importance of using a socio-technical viewpoint within their maturity model to improve warehousing processes in terms of autonomous warehousing, which is a key study in relation to this research that also adopts a socio-technical viewpoint. The socio-technical system elements of technology, organisation and people, provide a holistic analysis of warehouse maturity within autonomous progression (Ruile & Lichtsteiner 2022). Any process within a warehouse setting is built on organisational elements, technology and people working together, as well as understanding that digital transformation in logistics is more than just implementing technology as it also effects processes, stakeholder roles and communications (Ruile & Lichtsteiner, 2022).

5.3.2.6.5 Logistics Maturity Model for Service Enterprise (Lewandowska & Kosacka-Olejnik, 2018)

The logistics maturity model for the service industry is based on 3 core pillars: phases of logistics evolution and supply chain management, the supply chain operations reference model (SCOR) and logistics tools. This model outlines the logistics areas as plan, source, storage, distribution, and return. The performance measurement system in this model is based on the use of logistics tools widely known as best practices for improvement. 81 logistics tools were identified as being applicable for the services industry and were divided into 10 groups from warehouse management, transport management, inventory management, supply chain management, general management, performance management, financial management, problem-solving, IT and Eco-tools. The concept of this model is that when an organisation implements certain logistics tools for each of the logistical areas, it will increase maturity progression.

Overall, there are many maturity models such as the CMM targeting software engineering and development projects and both OPM3 and P3M3 targeting project management. In addition, the LMM in the subject area of Supply Chain and Logistics as explained above is highly effective, all of which are in place to improve organisations strategic thinking, systems and processes. The maturity models specifically developed for warehousing are also effective, however they focus on warehousing as a whole and improvement towards automation. The existing maturity models discussed lack the direct focus on IMS and its functions and processes involved from inbound to outbound logistics. Therefore, there is a need for a maturity model specifically targeting inventory management systems as its own key area within logistics to address inventory data related challenges.

Table 17 categories the existing maturity models reviewed based on their type, classifying them as descriptive, prescriptive, or comparative in nature. Table 17 shows that prescriptive models are the most common type of maturity models developed, as they help to both assess current maturity levels and provide action plans to improve maturity.

Table 17 Comparison of Maturity Models Against Type and Development Methodology

Maturity Models	**Type of Maturity model**		
	DESC	**PRESC**	**COMP**
Capability Maturity Model (CMM)	-	✓	-
Organisational Project Management Maturity Model/ Project Management Maturity Model (OPM3/P3M3)	-	✓	-
Stages of Growth (NSGT)	✓	-	-
Supply Chain Process Maturity Model (SCPM3)	-	✓	-
Logistics Maturity Model (LMM)	-	✓	-
Warehousing Function Maturity Model	-	✓	-
Autonomous Warehousing Maturity Model	-	✓	-
Logistics Maturity Model for Service Enterprise (LMMSE)	-	✓	-

Table 18 Comparison of Levels, Dimensions and Other Components Between the Existing Maturity Models in the Logistics Domain

Maturity Models	***Levels***	***Dimensions***	***Components/ other areas (Processes)***
Supply Chain Process Maturity Model (SCPM3) (De Oliveira, 2011) *Process Maturity Model*	Level 1: Foundation Building a basic structure aiming to create a foundation for the processes Level 2: Structure Processes start to be structured to be further integrated Level 3: Vision Process owners are established and become responsible for their management and performance results Level 4: Integration The organisational processes integrate with the processes of the suppliers and customers in a collaborative platform Level 5: Dynamics Processes support collaborative practices between partners and generate a baseline enabling the chain to be responsive to market changes	-	Processes: -Foundation Building -Order Management -Distribution Network Management -Demand Management & Forecasting -Production Planning and Scheduling -Procurement Team -Process Governance -Strategic Planning Team -Customer Integration -Supply Network Management -Strategic Behaviours -Collaboratively Integrated Processes -Responsiveness
Logistics Maturity Model (LMM)	Level 1: a business need is acknowledged but the related process is not managed	-	-

(Battista and Schiraldi, 2013) Process Maturity Model	Level 2: the process is managed but it is neither formalized nor standardized		
	Level 3: the process is formalized and standardized, but it is neither controlled nor monitored		
	Level 4: the process is controlled and monitored but it is not optimized		
	Level 5: the process is optimized		
Warehousing Function Maturity Model (Razik et al., 2017)	Level 1: Initial- there is no process areas and process is chaotic	Dimension 1: Maturity Level Dimensions	Components: Component 1: Warehouse design
	Level 2: Defined – the level where warehousing processes are documented, standardised and integrated into standard implementation process for the organisation	Dimension 2: The four main components of the warehousing function	Component 2: Warehouse Resources Component 3: Warehouse Operations
	Level 3: Managed – warehousing function process and activities are controlled and managed	Dimension 3: Critical Succes Factors for warehousing performance improvement	Component 4: Warehouse management
Autonomous Warehousing Maturity Model (Ruile & Lichtsteiner, 2022)	Level 1: Ignoring – no awareness of needs for integrating technology into operations	Processes People	Processes: Unloading
	Level 2: Defining – the need for integration is acknowledged but missing knowledge of implementation	Technology Organisation	Receiving Put Away Storage
	Level3: Adopting – basic steps for integration of advanced technology initiated		Picking Packing
	Level 4: Managing- integration is driven forwards affecting all business areas		Loading Shipping
	Level 5: Integrated – Top level of integration is established		

Logistics Maturity Model for Service Enterprise (LMMSE) (Lewandowska & Kosacka-Olejnik, 2018)	Level 1: Fragmentation Level 2: Consolidation Level 3: Functional Integration Level 4: Value adding Level 5: Network Level 6: Automation	-Plan -Source -Inventory/Storage -Distribution -Return	Groups of logistics tools: -Warehouse management tools -Transport management tools -Inventory management tools -Supply chain management tools - General management tools - Performance management tools - Financial management tools - Problem-solving tools -IT tools -Eco-tools

Table 18 presents the comparison of the existing maturity models within the logistics domain, the SCPM3, LMM, warehousing function model, autonomous warehousing model and the logistics maturity model for the servicing industry. The levels for each model, dimensions, if any and additional areas highlighted, such as processes or components attached to levels. The SCPM3 and the LMM are both process maturity models and do not consist of additional dimensions however, the SCPM3 attaches processes to each of the maturity levels, specifically focusing on improving these processes. The warehousing function and autonomous warehouse maturity models both contain specific dimensions in which the maturity will also be considered whilst also attaching additional components and processes that must be considered in the maturity model application. The logistics maturity model for the servicing industry highlights key areas to be addressed alongside the maturity levels, making use of the 81 tools grouped into the element categories to improve maturity overall. Table 18 shows that processes are a common component of maturity models.

5.3.2.7 Methodologies in Developing Maturity Models

This section presents the three main design and development methodologies for maturity models in published literature: De Bruin et al., (2005) six phases, Solli-Saether & Gottschalk (2010) five phases and Becker et al., (2010) eight phases. It is important to have a suitable methodological approach in place to assist with developing maturity models.

5.3.2.7.1 De Bruin et al., (2005) Six Phase

De Bruin et al., (2005) present a six phase approach to guide the design of a descriptive maturity model with advancement for prescriptive and comparative development. The phases outlined are: (1) scope, (2) design, (3) populate, (4) validate, (5) test and deploy and (6) maintain as shown in Table 19. This is an often-cited approach that assists in developing maturity models (Ruile & Lichtsteiner, 2022; Pöppelbuß & Röglinger, 2011).

Table 19 Six Phase Methodology to Maturity Model Development (Based on: De Bruin et al., (2005)

Phase 1- Scope	A decision must be made on if the model is going to be general or domain specific as this helps to determine the scope and boundaries of the model. Focusing the domain, will distinguish the proposed model from other models and this can be done by initially conducting an extensive review of existing literature in each domain and then making a scoping decision (De Bruin et al, 2005).

Phase 2 - Design	The design spans over five criteria to help determine the layout/architecture of the model in clarifying the audience, the method of application, respondents and the application itself. It is important not to oversimplify the model as it will not reflect the complexities of the domain and sufficient meaningful information. However, an overcomplicated model may cause incorrect application, resulting in misleading results. A common design principle in existing maturity models is to represent maturity in stages of 1 being low and 5 being high. Ensuring that the design of each element is all well-defined and that there is logical progression, this will result in a effectively designed maturity model (De Bruin et al, 2005).
Phase 3 – Populate	Population refers to the content and the description of the model components. This helps to understand what content is to be measured, which can be done through a rich literature review or empirical approaches such as stakeholder interviews, surveys and case studies. It is important to understand what needs to be measured in the maturity assessment and how it will be measured. Ensuring identification of the components will help with identifying the specific improvement strategies, particularly critical success factors and barriers can help give insights to potential components of a maturity model (De Bruin et al., 2005).
Phase 4 – Validate	Validity and reliability are important building blocks as it will help to strengthen the relevance and rigour of the model. Validity addresses the correlation between factual and intended measurements and reliability addresses if the results are accurate and repeatable. It is important to test both the construct of the model and each component for validity and reliability and this can be shown by the extent of the literature review and depth of domain providing a measure of content validity (De Bruin et al., 2005).
Phase 5- Test and Deploy	The model must be made available to use and clarify the generalisability of the model which can be achieved by applying the model in case studies (De Bruin et al., 2005)
Phase 6 - Maintain	It is important to maintain the model's growth and use to show that it can handle a high volume of application to support the models standardisation and acceptance as well as continued relevance (De Bruin et al., 2005).

5.3.2.7.2 Solli-Sæther and Gottschalk (2010) Five Phase

Solli-Saether & Gottschalk (2010) present a five-phase methodology as shown in Table 20 that particularly emphasises theoretical and empirical foundations for maturity model development. There are four main steps when theorising maturity models, firstly deciding on the number of stages, secondly identifying dominant problems to each stage showing primary concerns, thirdly identifying measurable variables which indicate each stage of growth and fourthly presenting the paths of evolution (Solli-Saether & Gottschalk, 2010).

The five phases in Table 20 present a goal-oriented process where the maturity model changes its status from a stage model to a conceptual stage model, a theoretical stage model, an empirical stage model, and finalising into a revised stage model (Solli-Saether & Gottschalk, 2010).   The development process enables the maturity model to evolve as new challenges emerge.

Table 20 Five phase Methodology to Maturity Model Development (Based on: Solli-Saether and Gottschalk (2010)

Phase 1- Suggested Stage Model	This initial stage model is derived from both research literature being evolutionary and from practitioners in practice with a perception on different maturity levels (Solli-Saether & Gottschalk, 2010).
Phase 2- Conceptual Stage Model	The number of stages and contents are developed in an iterative cycle that involve problems with different views at various stages. Each previous stage to the next have different dominant problems (Solli-Saether & Gottschalk, 2010).
Phase 3- Theoretical Stage Model	Theories are applied to explain the stages, contents and the development from one stage to the next (Solli-Saether & Gottschalk, 2010).
Phase 4- Empirical Stage Model	Each of the benchmark/measurable variables is assigned a value for each stage of growth and these values and evolution are then empirically tested (Solli-Saether & Gottschalk, 2010).
Phase 5- Revised Stage Model	Based on the empirical test, the empirical stage model is revised giving the finalised stage model (Solli-Saether & Gottschalk, 2010).

5.3.2.7.3 Becker, Knackstedt and Pöppelbuß (2009) Eight Phase

Becker et al., (2009) present another maturity model development methodology that is a procedure model based on Hevner (2004) design science research guidelines. Design science research (DSR) creates innovative artifacts such as models, methods and constructs that can cope with human and organisational challenges and is aimed at improving problem-solving (Becker et al., 2009; Pöppelbuß & Röglinger, 2011). In this case, the artifacts would be the maturity model, which serves to solve problems by determining the status of organisational capability and thereby offering improvements.

The methodology consists of eight phases for the design process that provide a manual for the theoretical founded and evaluation of maturity models (Becker et al.,2009):

1. Problem definition
2. Comparison with existing maturity models
3. Design strategy
4. Iterative development procedure
5. Transfer concept and evaluation
6. Implementation of transfer media
7. Evaluation of results
8. Iterative continuation and documentation.

This methodology is currently used by the European Research Centre for Information Systems (ERCIS) and Deloitte Consulting GmbH in the development of a maturity model to assess the application of IT performance measurement, (ITPM3). This model provides a tool for the enhancement of Business Intelligence (BI) applications within IT supported processes (Becker et al., 2009).

Overall, this section has presented three key maturity model design and development methodologies which advocate a step-by-step systematic approach for developing a maturity model. All methodologies emphasise operationalisation and appropriate empirical validation to ensure practice relevance (Becker et al., 2009). It can be concluded that there are no specific concrete rules for deciding an approach to developing a maturity model as there is no consensus among maturity model developers as to which approach and when it should be applied. However, it is important to note that using existing literature and validating the dimensions and developmental constructs of maturity models empirically is key (Lasrado et al., 2015; Monteiro & Maciel, 2020).

5.3.2.7.4 Approaches to maturity model development

5.3.2.7.4.1 Top-down

To assist in the specification of maturity models, two approaches are identified, (1) top-down and (2) bottom-up. The top-down approach starts by defining the maturity model stages, then creates dimensions, before adjusting the measurements and components

(Monteiro & Maciel, 2020). Definitions are written first and then measures are developed to fit the definitions (De Bruin et al., 2005). The top-down approach works more for newer domains where there is little evidence of what maturity is for the organisation (De Bruin et al., 2005; Monteiro & Maciel, 2020).

5.3.2.7.4.2 Bottom-up

The bottom-up approach to developing a maturity model first determines requirements and measurements and then writes stages and definitions (De Bruin et al., 2005; Monteiro & Maciel, 2020). The bottom-up approach works well in an established domain where an understanding of how to measure maturity has been established (De Bruin et al., 2005; Monteiro & Maciel, 2020).

Table 21 Mapping methodologies to type of approach selected

Methodology	*Approach*	
	Top- Down	Bottom-Up
De Bruin et al, (2005) 6 Phase	✓	
Solli-Saether and Gottschalk, (2010) 5 Phase	✓	
Becker et al, (2009) 8 Phase	✓	

Table 21 shows the mapping of the methodologies explored in Section 5.3.2.7 mapped to the top-down approach, showing that top-down approach is a widely selected approach to develop maturity models.

5.3.2.7.5 Paradigms to Specifying Maturity Models (Theoretical Considerations in Maturity Model Development)

There are three paradigms of specifying maturity models: normative theories, best practice guidelines and benchmarking tools (Monteiro & Maciel, 2020).

- Normative theories: This paradigm is grounded as process theories with events happening in a sequential way increasing in maturity. Most models adopt this structure, such as Nolan & Gibson (1974).
- Best practice guidelines: This is based on practical actions and reflects the best practices in a domain. They are organised through levels of effectiveness and

aim to help organisations by offering improvements with an implementation guide (Battista & Schiraldi, 2013; De Bruin et al., 2005)

- Benchmarking: This portrays the maturity model as a practice and organisations are benchmarked and compared against each other through low to high maturity. The SCPM3 maturity model is a benchmarking model.

A criticism of maturity models is that they lack a theoretical base, however process theory can be used to help substantiate the maturity path (Monteiro & Maciel, 2020). Process theory is classified in 4 groups: Lifecycle, evolution, dialectic and teleology, these can be used to conceptualise maturity.

- Lifecycle: This represents organic linear growth from the lowest to the highest level of maturity. Progression is irreversible with the driving force coming internally within the entity.
- Evolution: Maturity evolution is explained using the competitive survival mechanism, where the entity competes with similar entities for resources.
- Dialectic: Conflict theory is the motive for progression but Teleology follows logic of reaching goals to an imagined matured state.

It is important for maturity models to have a theoretical underpinning and these can be drawn from the existing theories as explained. These foundations can help to strengthen the development of the model, addressing potential criticism that maturity models lack theoretical considerations (Otto et al., 2020).

In summary, literature regarding maturity models and their types, existing maturity models developed in the logistics domain and methodologies for developing maturity models have been reviewed. The following section details the development of stage 2 of the framework, the inventory management system maturity model (IMSMM). De Bruin et al., (2005) maturity model development methodology has been adopted to ensure a structured and rigorous approach in developing the model.

5.3.2.8 Adopting De Bruin et al., (2005) Methodology to Develop the IMSMM

The following section outlines the stages of developing the IMSMM following the six phases of the De Bruin et al., (2005) methodology from Table 19.

5.3.2.8.1 Phase 1: Scope

The maturity model must be developed within the specific domain of inventory management systems within SMEs. Chapter 1, Section 1.4 outlines the domain of inventory management systems scope beginning from inbound inventory, storage of inventory and outbound inventory. The scope concerns the journey of managing inventory entering the warehouse environment, how it is processed and stored by the organisation and finally being prepared for shipment. The purpose of the maturity model is to assess and improve inventory data quality within the inventory management system to improve operational efficiency.

5.3.2.8.2 Phase 2: Design

The design and structure of the IMSMM are firstly informed by the literature, which identifies the IMS challenges so that a clear understanding is obtained as to what needs to be addressed to improve inventory data quality. Figure 13 in Chapter 2, Section 2.10.2, the matrix mapping, which shows the relationships between the IMS challenges, their causal factors, and the CSFs all mapped to the socio-technical OPPT approach, which informs the design of the maturity model. This ensures that relationships between all the elements are considered, and that the socio-technical approach is also embedded into the model addressing the research aim. Finally, Figure 25 in Section 5.2, outlines a group of activities in sub-system 2 of the conceptual model. This sub-system indicates the need to assess the current implementation of the IMS processes, technology and the staff’s attitudes and behaviours, showing how socio-technical approach can be embedded within the maturity model. This further informs the foundational basis of the maturity model.

5.3.2.8.3 Phase 3: Populate

5.3.2.8.3.1 Maturity Model Levels and Rationale

The maturity levels were designed to specifically address the challenges of the IMS outlined in Chapter 2, Section 2.6.1. This is to ensure that as the maturity of the IMS increases, the challenges identified are reduced or eliminated. In addition, the activities are the outputs produced by the system, form the maturity levels identifying levels of improvement.

The activities outlined in the output of the conceptual model were data captured accurately, data maintained accurately, data verified accurately, location data accuracy improved, forecasting data accuracy improved, and replenishment data accuracy improved. Table 22 outlines the developed maturity levels, their aim, outcome and rationale.

Each of the maturity levels will be assigned 100% to indicate maximum completion of a maturity level. This can then be used to calculate the overall maturity percentage after an IMS is assessed.

Table 22 Designed and Developed Maturity Levels

Maturity Level	***Aim***	***Outcome***	***Explanation***
Level 1: Data Capture Accuracy	The focus in this maturity level is to ensure that the initial data captured is accurate.	Accurate Transactions	Level 1 defines the transactions taking place, covering inbound receiving inventory transactions to shipping inventory transactions, ensuring that they are accurately recorded.
Level 2: Maintain Data Accuracy	The focus in this maturity level is to keep data consistently correct and error-free after it has been captured	Minimal Lost/Misplaced Inventory	Level 2 outlines maintaining minimal instances of lost/misplaced inventory and when incurred, it is addressed and rectified by placing the inventory in the correct place, and updating inventory levels to reflect changes.
Level 3: Verify Data Accuracy	The focus in this maturity level is to establish the processes for verifying the accuracy of data, often happening through auditing/validation processes	Accurate Inventory Levels	Level 3 outlines the importance of having accurate inventory levels through auditing, where there is no discrepancy between the system level and physical level of inventory and it all matches.

Level 4: Improve Location Data Accuracy	The focus of this maturity level is to enhance the accuracy of location-specific data for better decision making	Effective Inventory Storage	Level 4 concerns the importance of ensuring that inventory is assigned identification in the form of stock-keeping-unit (SKU) and is assigned locations throughout the warehouse space to efficiently manage the storage of inventory.
Level 5: Improve Forecasting Data Accuracy	This maturity level aims to ensure that forecasting data is correct to result in accurate forecasts of inventory	Accurate Forecasting	Level 5 ensures that accurate forecasting of inventory can be done using accurate inventory level data to inform decision-making and for reporting purposes.
Level 6: Improve Replenishment Data Accuracy	The focus of this maturity level is to fine-tune inventory level data accuracy for inventory replenishment, optimising re-ordering of inventory	Efficient Inventory Level Maintained	Level 6 ensures inventory levels are efficiently maintained to avoid instances of stock-outs occurring.

The outcome of each maturity level shows a direct relation to the IMS challenges in Section 2.6, emphasising that improvements in the levels also addresses the main IMS challenges outlined in the literature. The following section explains how the maturity levels map to the IMS challenges.

- Level 1- Data capture accuracy addresses IMS challenge: transaction errors: Recording inventory transactions incorrectly, results in inventory levels being inaccurate, impacting customers negatively, and potentially resulting in loss of sales.
- Level 2 – Maintain data accuracy addresses the IMS challenge: lost/misplaced inventory: Instances where inventory cannot be located, results in monetary loss as inventory equates to asset as it is therefore classed as inaccessible inventory. This also results in increased inventory costs as missing inventory, if not found, will need to be re-ordered to meet customer demand. This directly results in a

discrepancy between physical and recorded inventory. Therefore, it is important to maintain data accuracy.

- Level 3- Verify data accuracy addresses the IMS challenge: Inventory Inaccuracy: The discrepancy between physical and recorded inventory levels is a substantial problem, contributing to a 10% loss in profits (Tao et al., 2020). Up to 65% of stock keeping units are found to be inaccurate not corroborating with the physical level of inventory highlighting poor accuracy of inventory. Verifying by ensuring both system and physical inventory levels match ensures data quality.
- Level 4- Improve location data accuracy addresses the IMS challenge: poor inventory storage: Not having unique stock keeping units assigned to inventory and locations for each item impacts the handling of inventory. Resulting in wasted man hours to locate products. Misplacement of inventory due to ineffective storage assignment leads to loss in sales if inventory is not found to fulfil customer orders.
- Level 5- Improve forecasting data accuracy addresses the IMS challenge: forecasting errors: Forecasting is based on real-time inventory levels data and if forecasting is inaccurate, this will impact the flow of inventory to meet customer demand. Inaccurate inventory levels disrupt forecasting, potentially causing incorrect inventory amounts to be ordered/resulting in stock-outs.
- Level 6- Improve replenishment data accuracy addresses the IMS challenge: Stock-outs: Poor maintenance of inventory results in stock-outs where sufficient inventory is not available to meet customer demand, resulting in loss of sales, impacting the organisations reputation, and customer loyalty. Holding too much inventory can tie up capital of the organisation and can potentially result in dead inventory not being sold. Holding too little, can cause stock-outs showing incompetency as a company to meet customer demand timely and successfully.

The justification for designing the maturity levels in this order is that it follows the inventory journey through the processes of inbound, storage and preparing outbound inventory. In level– 1 data capture accuracy, recording all inventory transactions, specifically inbound accurately, is paramount for inventory levels to also be accurate. This leads to level 2- maintain data accuracy, where instances of lost/misplaced stock are addressed and rectified, ensuring inventory levels match on the system and physical level, ensuring that inventory level data accuracy is maintained. Moving into level 3- verify data accuracy, where auditing is important to ensure that inventory levels are verified and there are no discrepancies between system inventory level data and physical inventory levels. Maturity levels 1 and 2 directly feed into level 3 as those are significant factors that can disrupt the accuracy of inventory levels. Once all inventory data is accurate, it is important that inventory is managed in the right place; level 4- improve location data accuracy addresses giving a clear plan of where inventory should be placed using a floorplan by assigning a location/zone that is set and defined within the warehouse. This location data for inventory is then documented and maintained. Further moving onto level 5 – improve forecasting data accuracy, which ensures that accurate inventory forecasting can only be carried out using accurate inventory data for reporting and decision-making; therefore, the previous levels are important to address first. Finally, the last maturity level, level 6- improve replenishment data accuracy, ensures that efficient levels of inventory are maintained reducing instances of stock-outs happening as all levels prior lead into ensuring inventory is ready for successful fulfilment and shipping. Since transactions are accurate, minimal instances of lost/misplaced stock, accurate inventory levels, inventory is well managed and stored effectively and forecasts are correct, this will then reduce instances of stockouts happening as efficient inventory levels are being maintained according to accurate inventory data overall.

5.3.2.8.3.2 Maturity Model Dimensions

Table 23 Maturity Model Dimensions

Socio-Technical Dimensions	Explanation
Organisational	The organisational dimension covers critical success factors such as policies, budget and resource, staff training and staff competency
People	The people dimension covers critical success factors such as staff knowledge, behaviour and communication as well as embedding another socio-technical dimension named culture of the people within the organisation in their ways of working.
Process	The process dimension covers the critical success factors such as, standard operating procedures and integrating and aligning processes within technology/system in place.
Technology	The technology dimension covers critical success factors such as type of technology, integration of technology and performance of the technology.

The 5 maturity levels are assessed against critical success factors within 4 maturity dimensions: organisational, people, process and technology. The 4 maturity dimensions have been informed by the socio-technical lens required to view an inventory management system and assess it for improvement. This emphasises the importance of the interplay of the social and technical perspectives required to effectively improve inventory data quality and performance in IMS.

The socio-technical elements were selected from Figure 9 in Chapter 2, Section 2.5.6, showing the socio-technical view of IMS, as this perspective emphasises that achieving maturity in inventory data quality requires an STS approach. The socio-technical lens recognises that advancing through the maturity levels requires simultaneous progress across the 4 interdependent maturity dimensions whilst addressing and implementing the critical success factors between them. Figure 13 in Section 2.10.2, the matrix mapping showing the relationships between the IMS challenges and the CSFs, was also used to inform the dimensions. It shows how the dimensions can relate to the maturity levels outlined that address the IMS challenges and the CSFS that address the IMS challenges and their causal factors.

Figure 12 in Section 2.10.1, the conceptual model of the literature, shows the relevant CSFs assigned to address each challenge mapped to the relevant OPPT element. This then informs the selection of the CSFs assigned to each of the OPPT dimensions in the maturity model as items to be assessed in the maturity assessment. The number of items of what is being assessed in the dimensions varies across each dimension, with organisational consisting of 9 items, people consisting of 3 items, process consisting of 5 items, and technology consisting of 8 items all needing to be addressed. The dimensions will be given a total of 25% weighting so that the individual maturity level percentages can be calculated out of 25% across the OPPT elements, where these can be summed up to calculate the overall maturity percentage score to assign to the SME post maturity assessment.

5.3.2.8.4 Phase 4: Validate

Before undergoing official testing of the maturity model, the construction of the model needs to be verified. The maturity model was validated by cross checking the building blocks of the maturity model, the levels, dimensions and items, with the primary and secondary data documented in Chapter 2 and Chapter 4. The IMS challenges, their causal factors and critical success factors across the 4 socio-technical dimensions have been included in the maturity model to understand the aspects of an IMS that need to be assessed and improved to improve inventory data quality and operational efficiency.

5.3.2.8.5 Phase 5: Test and Deploy

The maturity model was tested to evaluate the effectiveness of using the maturity model to assess and improve data quality and operational performance in inventory management systems in SMEs. Using a chosen case study with the company name: Eco Clean, the maturity model was deployed to assess their inventory management system maturity level, and recommend improvement actions to enhance their maturity level percentage and improve inventory data quality. Whilst testing with a single case study has limitations, this is a common approach used in the field. For example, Ruile & Lichtsteiner (2022) tested their maturity models using a single case study. The testing of the maturity model is documented in Chapter 6.

5.3.2.9 Final Developed Inventory Management System Maturity Model

Table 24 Final Maturity Model

	Scope of Operations: IMS Activities – Receiving, Tracking, Replenishment, Location management, Shipping					
Socio-technical elements of IMS	1	2	3	4	5	6
	Data Capture Accuracy	**Maintain Data Accuracy**	**Verify Data Accuracy**	**Improve Location Data Accuracy**	**Improve Forecasting Data Accuracy**	**Improve replenishment data accuracy**
	Outcome: Accurate Transactions	Outcome: Minimal Lost/Misplaced Inventory	Outcome: Accurate Inventory Levels	Outcome: Effective Inventory Storage	Outcome: Accurate Forecasting	Outcome: Efficient Inventory Level Maintained
	(Transactions covering receiving to shipping inventory are accurate)	*(Instances of lost/misplaced inventory are minimal)*	*(Inventory levels match both on a documented/system and physical level)*	*(Inventory has SKUs & is being stored effectively i.e. locations/zones)*	*(Forecasting of inventory is done accurately with accurate inventory level data)*	*(Inventory levels are efficient to ensure instances of stock-outs do not occur)*
	Please ✓all that apply	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*
Organisation						
People						
Process						
Technology						
Total Maturity Level Percentage Across All OPPT Areas	**Out of 100%**	**Out of 100%**	**Out of 100%**	**Out of 100%**	**Out of 100%**	**Out of 100%**
Total Overall Maturity Percentage						

Socio-technical elements of IMS		1	2	3	4	5	6
Organisational	CSF: Policies	Inventory inspection (Quality checking on arrival, shipping and movement of inventory)	Correct & update inventory levels both on documented / system and physical level	Inventory Auditing (monthly / annual cycle count)	Stock keeping unit (SKU) assignment & Storage (locations, zones, class based, randomised)	Accurate forecasting practices	Replenishment policy: continuous review /periodic review/JIT/EOQ
	Action: Policy Defined						
	Action: Policy Implemented						
	Action: Policy Followed						
	CSF: Sufficient Resource						
	Action: Allocate resources to implement policy/processes						
	CSF: Sufficient Budget						
	Action: Allocate the budget to implement technology						
	CSF: Staff Trained						
	Action: Manual Handbook of Policy and SOPs						
	Action: Induction Training						
	CSF: Staff Competency						
	Action: Induction training on following processes/ using technology/system						
	Action: Monthly/Annual training renewal in following SOPs						
	Total %						

Socio-technical elements of IMS		1	2	3	4	5	6
People	CSF: Staff have satisfactory Knowledge/Awareness of importance						
	Action: Read the policies (marked on system- user credentials/ visually checked in person)						
	CSF: Staff display Appropriate Behaviour (Avoiding Human Error)						
	Action: Series of Mock errors to test staff						
	CSF: Staff communicate effectively						
	Action: Schedule scenario-based training to test communication skills						
	Total %						

Socio-technical elements of IMS		1	2	3	4	5	6
Process	CSF: Standard operating procedure	Standard Operating Procedure defined: Document movement of inventory from inbound to outbound. When inventory is received and shipped, it is to be inspected thoroughly to verify what has been received so that it can be updated correctly on both documented/system and physical level. Detail on how to rectify an inaccurately recorded transaction	Standard Operating Procedure defined for actioning instances where inventory being lost/misplaced is identified. Once located it is processed and placed back in the correct place and if not found it is also updating inventory levels to reflect the differences both documented/system/physical level.	Standard Operating Procedure defined: Conducting monthly and annual cycle counts of inventory ensuring levels are consistently updated reflecting the same on both documented/system /physical level. Set dates and team members are planned to initiate inventory audit across all held inventory. Detail on how to rectify instance of inaccurate inventory levels found by investigation	Standard Operating Procedure defined: Inventory is assigned unique SKUS, once inventory is received, it is processed and stored in correct locations and when moving inventory around it is stored correctly and updated both physical and documented/system level. Detail on how to rectify instance of mis-managed inventory not stored effectively	Standard Operating Procedure defined: review inventory reports, sales data and inventory levels to understand trends in data determining forecasts on inventory based on different variables aiding in decision making avoiding stock-outs. Detail on how to rectify inaccurate forecasts conducted	Standard Operating Procedure defined: From periodic/continuous reviewing inventory, following replenishment and placing a re-order point, order quantity for inventory when needed to maintain efficient inventory levels avoiding stock-out. Detail on how to rectify errors when stock-outs occur to minimise damage
	Standard Operating Procedures (SOP) Documented						
	Standard Operating Procedures (SOP) Implemented						

	Standard Operating Procedures (SOP) Followed						
	Action: Schedule silent observations to inspect staff on following SOPs in place						
	CSF: Processes integrated and aligned with technology/system in place						
	Action: Processes within SOP are regularly assessed, updated, maintained and signed off monthly						
	Total %						

Socio-technical elements of IMS		1	2	3	4	5	6
Technology	Technology Adopted: NONE Manual (Paper)						
	Technology Adopted: Spreadsheet IMS						
	Technology Adopted: Automated IMS						
	Technology Adopted: Integrated IMS						
	Technology Adopted: AI/AR/Robotics						
	Technology Adopted: Automated Identification Technology: Barcoding/RFID						
	CSF: Technology integrated with functions in IMS processes						
	Action: Inspect technology/system for misalignment to processes/policy/SOPs						
	CSF: Technology is performing as expected						
	Action: Performance audit of the technology/system monthly and annually						
	Total %						

Table 24 presents the final developed inventory management system maturity model (IMSMM) as stage 2 in the framework to improve inventory data quality in inventory management systems within an SME. After adopting De Bruin's et al., (2005) methodology to develop the maturity model, the final model consists of 6 maturity levels and 4 dimensions. A socio-technical lens is represented through the 4 dimensions as: organisation, people, process and technology. Critical success factors have been assigned to the relevant STS dimensions within the model as items to be assessed in the maturity assessment. The sets of CSF items within each of the dimensions are to be assessed across each of the 6 maturity levels, to ensure the holistic view on the IMS and emphasising the need for joint optimisation across OPPT for the IMS to improve inventory data quality. The maturity model addresses the lack a specific maturity model in the literature to assess IMS in SMEs to improve inventory data quality. The next section outlines the formulas required to calculate the overall maturity percentage.

5.3.2.10 Design of the Formula to Calculate the Maturity Percentage

Phase 5 of the De Bruin et al., (2005) methodology requires the maturity model to be tested and deployed. It was identified that a quantifiable measure of impact of the IMSMM was needed to test the model. This section documents the design of a formula to calculate the overall maturity percentage based on weightings and percentages for the maturity levels and dimensions stated in the design of the model in section 5.3.2.8.3.

5.3.2.10.1 Statistical Modelling – Overall Maturity Index

Statistical modelling was used to calculate the overall maturity percentage, creating a statistical formula titled 'Overall Maturity Index' (OMI). This is based on weightings and percentages for the maturity levels and dimensions stated in the design of the model in Section 5.3.2.8.3. The OMI provides a composite score that reflects the overall maturity level based on the specific dimensions and weighted average within the IMSMM. The quantitative statistical method used within the OMI is related to 'weighted scoring methods' and 'aggregate indices', a commonly used method in multi-criteria decision-analysis and performance evaluation (Menzies et al., 2022, Ayan et al., 2023).

5.3.2.10.2 Multi-Criteria Decision Analysis (MCDA)

Weighted scoring and aggregate indices have strong foundations within multi-criteria decision analysis (MCDA) as they provide structured approaches to evaluate and prioritise alternatives based on multiple criteria. These specific methods within MCDA involve assigning weights to criteria to reflect their relative importance and aggregate scores to determine overall rankings (Menzies et al., 2022, Ayan et al., 2023). Olguin et al., (2021) explain the classic multi-criteria technique: Weighted Sum Model (WSM), where firstly the criterion is determined, secondly the corresponding weights must be assigned and then finally the application of the algorithm takes place to apply the criteria.

5.3.2.10.3 Previous Studies of MCDA In the Field

MCDA has been applied in areas of evaluation in a study regarding competency of the workforce in the industry. This directly relates to measurement of competency in this research where 'maturity' of an SMEs inventory management system is measured across the 5 maturity levels and 4 socio-technical dimensions. Theeranuphattana (2012) explains a study where an innovative measurement method was developed that aggregates performance measures in a supply chain into an overall performance index. This study links approaches and techniques within MCDA, like the swing weighting method, for the comprehensive assessment of supply chain performance, showing how MCDA has been used in the supply chain logistics domain. Another study by Žic & Žic (2020) shows the use of the MCDA technique, the weighted sum model (WSM), pertaining to analysing the correlation and interdependencies between inventory levels, costs and emissions within a supply chain echelon, further presenting the use of MCDA techniques within supply chain and logistics. Henry (2024) presents a study exploring MCDA techniques to address logistics optimisation problems such as vehicle routing, warehouse location and inventory management. In particular, the use of the technique TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) to prioritise inventory policies based on demand patterns and carrying costs, and the use of MAUT (Multi-Attribute Utility Theory) employed to evaluate stocking policies to help address uncertainties in demand fluctuations leading to resilient inventory strategies (Henry, 2024). These publications provide insights into how MCDA methods are applied within the main field of supply chain and logistics, showing its relevancy in using within this research. This next section presents the use of MCDA techniques to measure the performance of an IMS by assigning an overall composite maturity level percentage.

5.3.2.10.4 Use of MCDA Techniques Within This Research

The OMI describes a composite score that reflects the overall maturity percentage. The formula summarises a maturity level percentage across the 5 maturity levels and 4 socio-technical dimensions, allowing for a consolidated view of maturity. The weighted scoring/sum model and aggregated indices techniques have been used to inform the development of the OMI where the weighted scoring method assigns equal weighting to each dimension in the maturity model (Organisation, People, Process and Technology) and calculates the scores by summing the weighted contributions. This technique has been used due to weightings assigned to each of the dimensions and maturity levels, which need to be considered when calculating the scores.

The formula:

1. Aggregate the weighted values from the different maturity levels and dimensions
2. Averages of the aggregate values, to provide an overall index that summarises the maturity across the 5 maturity levels and 4 dimensions

Aggregating indices is useful when dealing with numerous criteria in the maturity model as there are multiple variables, therefore, this technique provides a unified measure of performance in this case the overall maturity percentage.

5.3.2.11 Development of the Overall Maturity Index Formula to Calculate Maturity Percentage

5.3.2.11.1 Define Variables

$\boldsymbol{M}$ **=** Total Number of Maturity Levels (Level 1 to 5, M = 5

$\boldsymbol{D}$ **=** Total Number of Dimensions (Organisational, People, Process, Technology, D = 4)

$\boldsymbol{P_{i,j}}$ **=** Maturity Percentage for dimension 'j' in maturity level 'i'

i = Represents maturity levels (i =1,2,3,4,5)

j = Represents dimensions (j =1,2,3,4)/ (1= Organisations, 2= People, 3= Process, 4= Technology)

5.3.2.11.2 Calculate the Maturity Percentage for Each Maturity Level Across all 4 dimensions

To calculate the maturity percentage for each maturity level i , the maturity percentages across all 4 dimensions need to be summed up. Based on the individual items within the 4 dimensions being assessed in the maturity model, the formula has been stated in the second column of the table as $\frac{25}{number\ of\ items} * n✓ =$ which is used to calculate the individual maturity percentages across the 4 dimensions within each maturity level i. This is presented in Table 25.

Table 25 Formula and Variables to Calculate Maturity Percentage for each Maturity Level

Maturity Levels / **Dimensions**	**Formula**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Organisational	$\frac{25}{9} * n✓ =$	$P_{1,1}$	$P_{2,1}$	$P_{3,1}$	$P_{4,1}$	$P_{5,1}$
People	$\frac{25}{3} * n✓ =$	$P_{1,2}$	$P_{2,2}$	$P_{3,2}$	$P_{4,2}$	$P_{5,2}$
Process	$\frac{25}{5} * n✓ =$	$P_{1,3}$	$P_{2,3}$	$P_{3,3}$	$P_{4,3}$	$P_{5,3}$
Technology	$\frac{25}{8} * n✓ =$	$P_{1,4}$	$P_{2,4}$	$P_{3,4}$	$P_{4,4}$	$P_{5,4}$

The following formula sums up the maturity percentages for the 4 dimensions (Organisational, People, Process and Technology) to obtain the individual maturity percentage for a specific maturity level i :

$$Maturity\ Percentage\ for\ Level\ i = \sum_{j=1}^{D} P_{i,j} = P_{i,1} + P_{i,2} + P_{i,3} + P_{i,4}$$

5.3.2.11.3 Calculate the Overall Maturity Percentage

The formula calculates the overall maturity level percentage, as the mean of the sum of all maturity percentages of each level then divided by the number of maturity levels (M = 5):

$$Overall\ Maturity\ Level\ \% = \frac{\sum_{i=1}^{M} \sum_{j=1}^{D} P_{i,j}}{M}$$

Since $M = 5$ and $D = 4$, this expands showing the summation of maturity percentages for all 4 dimensions across each of the 5 maturity levels, averaged to get the overall maturity level percentage:

$$Overall\ Maturity\ Level\ \% = \frac{(P_{1,1} + P_{1,2} + P_{1,3} + P_{1,4}) + (P_{2,1} + P_{2,2} + P_{2,3} + P_{2,4}) + (P_{3,1} + P_{3,2} + P_{3,3} + P_{3,4}) + (P_{4,1} + P_{4,2} + P_{4,3} + P_{4,4}) + (P_{5,1} + P_{5,2} + P_{5,3} + P_{5,4})}{5}$$

The structure of the formula uses a double summation:

1. **Inner Summation -** $\sum_{j=1}^{D} P_{i,j}$ calculates the total maturity percentage for each level i by adding the maturity percentages from each dimension (Organisational, People, Process and Technology).
2. **Outer Summation –** $\sum_{i=1}^{M}$ sums together the maturity level percentages across all levels, finally resulting in the total maturity across all maturity levels.
3. **Averaging –** Once the summation is completed, the result is then divided by the total number of maturity level (**M = 5**). This division provides the mean maturity level as a percentage out of 100%.

The 'Overall Maturity Index' is a statistical tool that averages maturity level percentage scores across multiple levels and dimensions to give a single view of maturity. Within the statistics domain, it can also be referred to as 'Arithmetic Mean' or 'Double Summation Average', where in this research an average is taken across two indices: levels and dimensions.

5.3.3 Stage 3: Development of Stating and Implementing Recommended Actions

Stage 3 of the framework details the recommended actions given to the SME when their initial maturity level percentage has been assigned, informing them of what improvements need to be implemented to improve their overall maturity across 5 maturity levels within 4 dimensions. The conceptual model in Section 5.2 details the sub-system 3 activities which inform the development of stage 3, indicating the actions that need to be taken to improve the IMS based on the previous information gathered from stage 1 and stage 2. The development of the recommended actions are essentially the critical success factors embedded within each of the 4 dimensions, which were informed by the literature findings on addressing the IMS challenges in Chapter 2, Section 2.6. The critical success factor items within the maturity model that the organisation has not addressed from the list of recommended actions necessary for achieving 100% maturity across each of the 4 dimensions and 5 maturity levels.

5.4 Relationship Between Data Quality Measures, Maturity Levels and Recommended Actions

The data quality measures identified within Chapter 2, Section 2.7.5 have been mapped to the maturity levels, indicating how the data quality measures have been embedded within the maturity model, to ensure that inventory data quality is improved as a result of maturity improvement of an IMS. Each maturity level involves progressive actions to improve data quality.

5.4.1 Level 1- Data Capture Accuracy

Aim: The focus in this maturity level is to ensure that the initial data entry captured is accurately.

Inventory Data Type: Incoming supplier deliveries and processing inventory being received and stored in the warehouse.

Table 26 lists the data quality measures related to this level in the maturity model.

Table 26 Level 1 Associated Data Quality Measures

Data Quality Measure	Explanation
Accuracy	The data captured is critical to ensure correctness and error-free data during the initial capture.
Timeliness	The data captured must be relevant to ensuring it is captured in a timely manner to avoid delays.
Completeness	The data captured must ensure all required fields are complete during data entry.
Ease-of-Understanding	The data captured should be clear and straightforward to understand.

5.4.2 Level 2- Maintain Data Accuracy

Aim: The focus in this maturity level is to keep data consistently correct and error-free after it has been captured.

Inventory Data Type: Maintaining inventory level data, by reducing instances of lost/misplaced inventory and rectifying these instances to reflect accurate data.

Table 27 lists the data quality measures related to this level in the maturity model.

Table 27 Level 2 Associated Data Quality Measures

Data Quality Measure	Explanation
Consistency	The data maintained must ensure that it is consistent over time and across different systems being used.
Reliability	The data maintained should be dependable and consistently accurate, especially using this data for decision making.
Validity	The data maintained must ensure that it continues to represent what it is supposed to measure, meeting the organisations standards.
Traceability	The data maintained must be able to help track data changes and updates to maintain accuracy.
Usability	The maintained data must be simple and practical so it can easily be utilised by all stakeholders involved.

5.4.3 Level 3- Verify Data Accuracy

Aim: The focus in this maturity level is to establish the processes for verifying the accuracy of data, often happening through auditing/validation processes.

Inventory Data Type: Verifying inventory level data is accurate through auditing.

Table 28 lists the data quality measures related to this level in the maturity model.

Table 28 Level 3 Associated Data Quality Measures

Data Quality Measure	***Explanation***
Reliability	The data verified ensures that it can be used to minimise system errors and that decisions can be made due to reliable criteria and information.
Validity	The data verified should comply with standards during verification to ensure that the data is valid and represents what it intends to.
Traceability	The data verified ensures that the auditing and data changes can be traced back to their origins and journeys of auditing followed.
Relevancy	The data verified is only relevant and necessary.
Ease of Use	Verifying data processes should be straightforward and easy to follow.

5.4.4 Level 4- Improve Location Data Accuracy

Aim: The focus of this maturity level is to enhance the accuracy of location-specific data for better decision making.

Inventory Data Type: Improve Inventory data location and storage to ensure inventory is stored adequately.

Table 29 lists the data quality measures related to this level in the maturity model.

Table 29 Level 4 Associated Data Quality Measures

Data Quality Measure	***Explanation***
Accuracy	This ensures that the location data is specific and correct, suitable to the inventory.
Integration	The integration of location data is seamless with other systems/records.
Clarity	The location data is presented clearly and concisely.
Efficiency	The location data processes should be conducted efficiently.
Value-Added	When location data is improved, this will enhance the value added of location data to aid in decision making etc.
Traceability	This ensures location data is updated and documented well showing audit trail of updates regarding location data changes.

5.4.5 Level 5- Improve Forecasting Data Accuracy

Aim: This maturity level aims to ensure that forecasting data is correct to result in accurate forecasts of inventory.

Inventory Data Type: Accurate forecasting data to ensure accurate and informative inventory forecasting to aid in decision making.

Table 30 lists the data quality measures related to this level in the maturity model.

Table 30 Level 5 Associated Data Quality Measures

Data Quality Measure	***Explanation***
Accuracy	Correct and error-free forecasting data is crucial for preparing inventory forecast reports on decision making.
Timeliness	Data should be up to date to ensure timely inventory forecasts when needed to aid in timely decision-making
Relevancy	Only relevant inventory data should be used to inform the forecasting of inventory to avoid delays/errors in inventory forecasts or reporting.
Completeness	Data must be complete and whole for accurate forecasts, accurate inventory level data and accurate transactions recorded in full are required for inventory forecast reporting

5.4.6 Level 6- Improve Replenishment Data Accuracy

Aim: The focus of this maturity level is to fine-tune inventory level data accuracy for inventory replenishment, optimising the supply chain efficiency.

Inventory Data Type: Improve replenishment level data to ensure reduced/low instance of stock-outs.

Table 31 lists the data quality measures related to this level in the maturity model.

Table 31 Level 6 Associated Data Quality Measures

Data Quality Measure	***Explanation***
Accuracy	Correct and error-free replenishment data is crucial for re-ordering inventory decisions.
Timeliness	Data should be up to date to ensure timely and accurate replenishment planning.
Relevancy	Only relevant inventory data should be used to inform the replenishment to avoid delays/errors in replenishment.

Completeness	All necessary data points required for replenishment should be complete and whole (inventory levels, supplier information, lead times, capacity).
Efficiency	Managing replenishment data should be streamlined and resource-efficient.

Table 32 visually shows the mapping of the data quality measures to the maturity levels.

Table 32 Mapping of Data Quality Measures to the Maturity Levels

Maturity Levels		**Data quality Measures**														
		Accuracy	Completeness	Timeliness	Consistency	Ease of understanding	Clarity	Ease of use	Usability	Relevancy	Value added	Validity	Traceability	Integration	Efficiency	Reliability
Level 1	**Data capture accuracy**	●	●	●		●										
Level 2	**Maintain data accuracy**				●				●			●	●			●
Level 3	**Verify data accuracy**							●		●		●	●			●
Level 4	**Improve location data accuracy**	●					●				●			●	●	
Level 5	**Improve replenishment data accuracy**	●	●	●						●					●	

The maturity levels defined in the IMSMM progress from capturing (Level1), maintaining (Level2), verifying (Level3) and improving data (Level 4,5,6). The importance of the different data quality measures in alignment with the maturity levels also help to progress the following within each level:

- Level 1- (Capture): Emphasises the foundational data quality, ensuring the data captured initially is correct.
- Level 2- (Maintain): Ensures that the data captured remains accurate over time.
- Level 3- (Verify): Strengthening the accuracy of the data captured and maintained through different validation mechanisms.
- Level 4, Level 5 & Level 6- (Improve): Both levels require advanced data quality, specifically focusing on accuracy, completeness, and data integration for decision-making purposes.

The data quality measures are integral to each maturity level defined in the IMSMM and directly influence the maturity assessment of inventory data quality. By assessing and improving the data quality measures, the IMS maturity can also be elevated, ensuring that the inventory data is accurate and of high quality.

5.4.7 Impact Levels of the Selected Data Quality Measures

Impact levels of low, moderate and high have been assigned to data quality measures to understand the impact of the maturity model levels on improving data quality. This is presented in Table 33.

Table 33 Data Quality Measures and Respective Impact Levels

Data Quality Measure	Low Impact	Moderate Impact	High Impact
Accuracy	Frequent errors/inaccuracies in the data, leading to low confidence in data	Few errors/inaccuracies and require some manual correction, generally considered reliable.	Data consistently accurate with minimal to no errors, high confidence in data.
Timeliness	Delayed or often outdated data reducing its usefulness.	Data is occasionally late or not updated frequently,	Data is always available timely when needed,

		generally available within accepted timeframe.	promptly updated.
Reliability	Regular inconsistency over time, lack of trust for decisions.	Data is mostly trusted but contains occasional discrepancies requiring verification before using.	Data is dependable consistently with a strong record of data being reliable and accurate.
Traceability	Any changes to data are poorly documented, not tracked and is difficult to trace back and identify the chain of error.	Some of the data changes are traceable, but process of documenting is not followed, leading to some tracing difficulties.	All changes are well-documented and have a clear audit trail, making it easy to follow the data origins and modifications done.
Completeness	Large parts of data are incomplete, impacting use of the data	Some parts of the data are occasionally incomplete, however core data is present	Comprehensive and complete data with all necessary areas filled giving the full picture of analysis
Relevancy	The data collected is often irrelevant leading to cluttered data.	Some data is not directly useful but most of the data aligns with requirements.	Data is all aligned, relevant and useful for decision making.
Value-added	Data lacks value and rarely supports decision making, unsure of the use of the data.	Data is occasionally useful but value contribution could be improved.	Data is consistently adding value, optimised and providing high value contribution.
Ease-of-understanding	Data is confusing, and difficult to interpret.	Some of the data is understandable, but some of the complexity requires further clarification.	Clear, well-presented data making it easily interpretable.

Integration	Data does not integrate with other systems, causing errors.	Limited data integrations with other system, causing few errors	The data is seamlessly integrated with other systems, enabling smooth data exchange error-free.
Clarity	Presentation of data is unclear causing misinterpretations of the data	Data is clear occasionally but has some errors requiring further clarification.	Presentation of data with clarity with no confusion, ensuring it is well understood.
Efficiency	Processing of data is slow and resource intensive, leading to inefficiencies and delays.	Processing of data is occasionally quick with some delays with high resource cost.	Processing of data is quick, efficient ensuring smooth workflows with timely results and no additional resource cost.
Ease of Use	Data is difficult to use and interpret.	Data is occasionally user-friendly, with some improvements needed.	Data is easy to navigate, resulting in high user satisfaction.
Validity	Data fails to meet validation criteria, leading to errors and manual corrections.	Some of the data is valid, however some needs adjustment to ensure it is valid for use.	Data is consistently valid, trusted to be used with very few exceptions.
Consistency	Data is very inconsistent, leading to misalignments and confusion.	Some inconsistencies present in the data but can be resolved.	Data is consistent, with no errors, conflicts or complexities ensuring clarity.
Usability	Data is inaccessible and unclear, limiting its chance of use.	Data is usable occasionally, but some barriers resulting in some instances of misuse of data.	Data is accessible, clear and well organised, supporting its use for decision making.

5.4.7.1 Converted Qualitative Impact Levels to Quantitative Measure of Impact

Data quality measures are needed to track improvements in data quality after implementing actions recommended from the IMS maturity model assessment. To do this, the qualitative impact levels assigned to each data quality measure (low, moderate, high) in Table 33 need to be assigned a numerical value. In that case, it directly shows an improvement in its quantitative data quality score. The following qualitative measures for impact have now been assigned a number so that impact can be measured quantitatively.

- **Low Impact –** 1 (Representing Poor Performance)
- **Moderate Impact –** 2 (Representing Acceptable Performance)
- **High Impact –** 3 (Representing Excellent Performance)

5.4.8 Development of the Formula to Calculate Quantifiable Data Quality Impact

This section outlines the development of the formula required to calculate the quantifiable measure of impact on data quality.

5.4.8.1 Define Variables

This formula developed will first calculate the individual percentage improvement of each data quality measure.

$\boldsymbol{S}_{original}$ = Original measure assigned before maturity assessment

$\boldsymbol{S}_{final}$ = Final score assigned after maturity assessment and recommended actions

$\boldsymbol{S}_{min}$ = Minimum Score for Low Impact

$\boldsymbol{S}_{max}$ = Maximum Score for High Impact

5.4.8.2 Calculate Individual Data Quality Improvement Percentage

Expression of the individual data quality improvement percentage formula:

$$Individual\ Data\ Quality\ Measure\ Improvement\ \% = \frac{\boldsymbol{S}_{final} - \boldsymbol{S}_{original}}{\boldsymbol{S}_{max} - \boldsymbol{S}_{min}} * 100$$

5.4.8.3 Calculate Overall Data Quality Improvement Percentage

The formula calculates the overall data quality improvement percentage as the sum of all individual data quality measure percentages, then divided by the number of data quality measures (data quality measures in total: 15).

$$Overall\ Data\ Quality\ Improvement\ \% = \frac{\sum i15}{15} * 100$$

5.4 Chapter Summary

This chapter documents the development of the framework to improve data quality in IMS, implementing the conceptual model formed in Chapter 4. The 3 sub-systems of the conceptual model formed the 3 stages of the framework. Stage 1 of the framework outlines the Inventory Management Context Capture Tool (IMCCT), which understands the situational context of an SMEs IMS. Stage 2 of the framework outlines the Inventory Management System Maturity Model (IMSMM) that was developed using De Bruin et al., (2005) methodology. Stage 3 of the framework discusses the recommended actions to initiate the improvements recognised post-maturity assessment. The chapter then presented formulas created to calculate the IMS maturity and measure the improvement of inventory data quality from implementing actions recommended in the maturity model. The framework is a core contribution of this research to improve inventory data quality in inventory management systems within SMEs.

6 Testing & Evaluation of Framework

6.1 Introduction

This chapter documents how the framework developed in Chapter 5 has been tested to assess and improve the inventory data quality in inventory management systems. First, a case organisation is outlined, and then the approach taken to test the framework in the case organisation is documented. The results of the testing are presented in this chapter. The chapter concludes by evaluating the framework's effectiveness in improving the quality of inventory data in the SME organisation.

6.2 Selecting Case Organisation – Eco Clean Ltd

A case organisation was used to test the framework in order to explore one bounded system over a period of time, allowing sufficient time for the actions recommended in the framework to be implemented and for the impact to be measured. The criteria used to select the case study organisation was that the organisation must be an: SME organisation trading in e-commerce retail, with inventory type finished goods and operating fulfilment within a warehouse environment. The criteria aligns with the scope of the research specified in Section 1.4.

An SME, referred to in this research as Eco Clean, met the selection criteria. Eco Clean is an SME specialising in eco-friendly laundry cleaning products sold online, direct to consumer and retail businesses. The framework was implemented in Eco Clean to assess the current maturity of its IMS and recommend actions for improvement. Eco Clean then implemented the recommended improvement. The impact of the implemented improvements was evaluated over a 6-month period from January 2024 to June 2024.

Stage 1 details the data collected from the case study to gain an in-depth understanding of the situational context of their IMS through a semi-structured interview using the IMCCT. This enabled stage 2 which applies maturity model assessment to assess the IMS across 5 maturity levels and 4 maturity dimensions, providing a composite overall maturity percentage score using the overall maturity index (OMI) formula developed. Finally, stage 3 outlines the recommended actions for improvements which is provided based on the overall maturity percentage score. Post implementation of the recommended actions, the overall maturity percentage score is recalculated to show an improved overall maturity percentage.

6.3 Test Plan

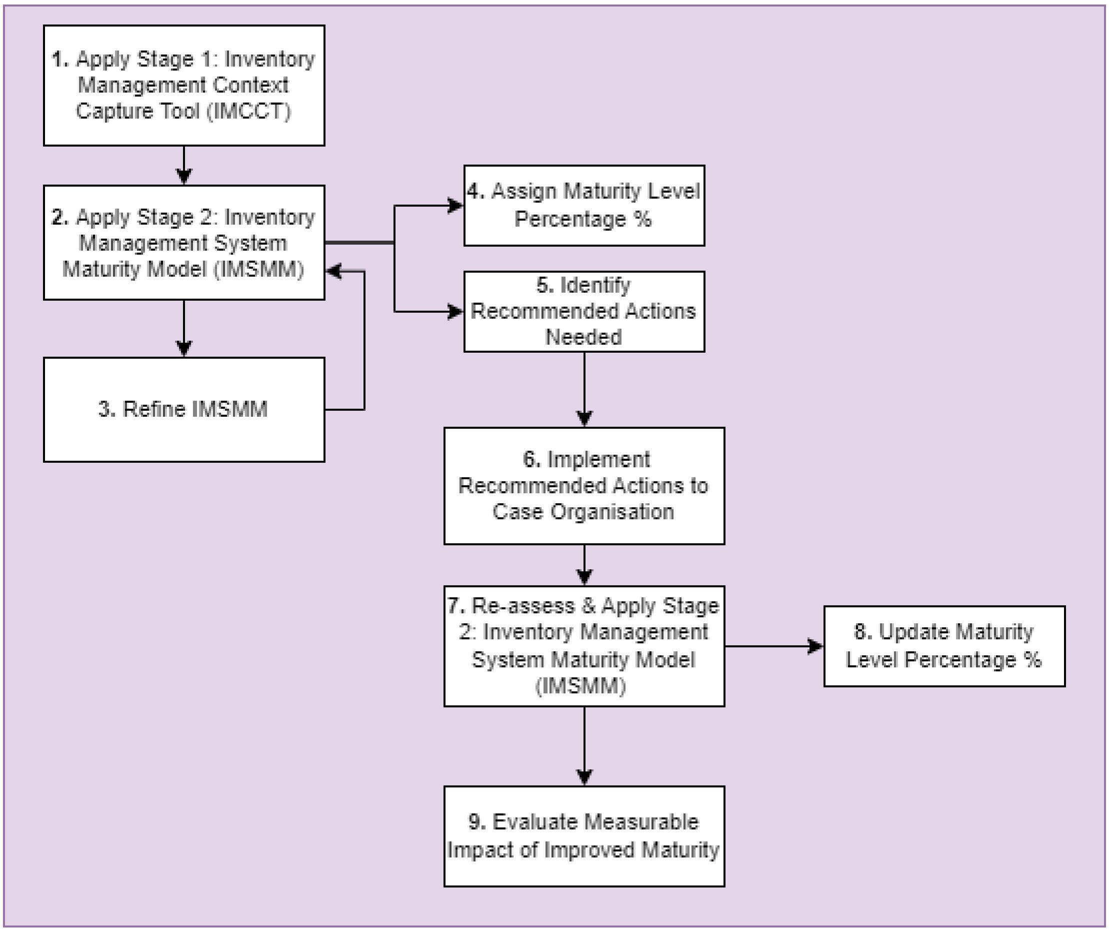

Figure 27 Framework Test Plan

Figure 27 visualises a workflow showing the plan for testing the framework with Eco Clean. Stage 1 of the framework, the Inventory Management Context Capture Tool (IMCCT), was used to collect data from the Eco Clean using a semi-structured interview, in order to understand the situational context of their IMS. Stage 2 of the framework, the Inventory Management System Maturity Model (IMSMM) was completed with the company's inventory manager to assess the IMS across the 5 maturity levels and 4 maturity dimensions. The application of the IMSMM with the company's inventory manager was then reviewed to determine whether the IMSMM needed to be refined. The composite maturity percentage of the IMS was then calculated using the overall maturity index (OMI). Stage 3 of the framework was used to recommend actions for the organisation to implement to improve the maturity of its IMS. Once the recommended actions had been implemented over a period best suited to the SME, the maturity model was re-applied and the IMS maturity level percentage was recalculated to determine where inventory data quality had been improved. The following sections document the implementation of the test plan with the selected case organisation Eco Clean.

6.3.1 Stage 1: Implement the Inventory Management Context Capture Tool (IMCCT)

This section presents the implementation of Stage 1, the Inventory Management Context Capture Tool (IMCCT) to obtain a clearer understanding of the SME organisation and the current state of their inventory management system. A semi-structured interview was undertaken to go through the questions outlined within the IMCCT tool. The interview was conducted with Eco Clean's Inventory Manager onsite within the warehouse environment to implement the IMCCT tool and collect the necessary data to understand the situational context of the organisation's inventory management system.

6.3.1.1 Testing the Inventory Management Context Capture Tool (IMCCT)

Figure 28 presents the completed IMCCT showing the organisational data from Eco Clean. The IMCCT shows an overview of their organisation, inventory and IMS. The tool shows top- level details populated in the 3 sections, however a detailed version is presented in Appendix 2.

Figure 28 and Appendix 2 highlight the current state of IMS and the IMS challenges being experienced at Eco Clean. Some of the key challenges faced relate to human errors occurring in all workflows; supplier issues with sending incorrect inventory; poor storage of inventory as there are no set locations for organising inventory, leading to regularly occurring instances of misplacements and mix-ups of similar inventory products; and inaccurate forecasting and replenishment of inventory causing delayed orders. These challenges contribute to a high discrepancy rate in inventory level data, causing monetary losses of around £22,000 due to the inaccuracies.

6.3.1.2 Review of Inventory Management Context Capture Tool (IMCCT)

The IMCCT provided clear understanding of the organisation's current IMS. This information was also used when conducting the maturity assessment in the next stage. Obtaining detailed data in the initial stage allowed for more preparation in the maturity model assessment stage as it provided a greater understanding of the organisation's current IMS and the inventory data challenges being experienced. Dingley (1995) stated that although originally tools to capture context were thought to be an optional stage only required by external consultants to familiarise themselves with an organisation, results showed that the activity is useful for internal staff, too. In this research, the inventory manager found that the IMCCT provided a useful opportunity to reflect on the role of the IMS in the organisation. It was found that the IMCCT tool helps to situate the consultant and internal staff, to understand the organisation's current state of the IMS and understand the inventory management terminology used in the organisation to work better with the client organisation.

Organisation Details

Company Name: Eco Clean

Date: 1st January 2024

Department: UK Warehouse Operations

Sales Channel (Shopify, Amazon, Ebay, Independent): Shopify E-commerce Store

Company Size (Small, SME, Large): Small to Medium Enterprise

Employees size: 5

Multi-channel Inventory Management: Online/Retail

Customer (B2C/B2B): B2C & B2B

Inventory Overview

Product Range: Eco Cleaning Products

SKUS assignment: Yes

How many SKUS in total: 10

Inventory Storage (Shelves, Pallets/Bins): Pallets, Overstock placed in storage units off site

Total Inventory investment: £750,000

Type of Inventory (Perishable/Non-Perishable: Non-Perishable

Nature of Inventory: Raw materials, WIP, Finished goods: Finished Goods

Organisational Overview

Identify typical workflows and how they work (Receiving, Processing, Tracking, Order Fulfilment, Inventory audit):

Receiving Inventory
Order Fuflilemt
Stock Replenishment
Inventory Audit
Returns

Any integrations in place:
Shopify
Royal Mail
Spreadsheets

Are the integrations working correctly:

Not efficient

Data synchronisation (Real-Time sync of inventory data):
No

Process Documentation (Processes/ SOPs in place):
No

Re-ordering efficiency (Delays in re-ordering):
Not specifically but 90 days roughly

Supplier Lead Times:
Cannot order on demand

Supplier performance in relation to inventory sent:
Poor, frequent errors

Warehouse Layout/Storage Space:
Small with not specific documented layout

Are there any KPIs in place (stockouts, accuracy):
Only order fulfilment

What technology is implemented:
None

What system is in place (manual, Spreadsheet, automated):
Spreadsheet + Automated on Royal Mail Client side

Is this working effectively:
No validation, human error etc

Are staff trained effectively:
7/10

Are there any plans to upgrade software, new technology?
New OMS, Barcoding

Which of these challenges are currently faced and frequency:

- Inaccurate transactions (Inbound/Outbound) ✓

- Lost/Misplaced Inventory ✓

- Inaccurate inventory levels (Discrepancies) ✓

- Ineffective inventory storage (Storage assignment) ✓

- Inaccurate Forecasting: Only occured once, since rectified

- Inefficient inventory levels maintained (Stock-outs) ✓

- Human Errors: ✓

Please detail any further challenges that are relevant:
Staff training/ Competency

Identify stakeholders interacting with/affected by inventory management:

Internal:
Inventory Manager, Warehouse crew staff, Accounts Team, Customer Service Team, Products department

External (Suppliers, Logistics Partners Shipping):
Suppliers,
Inbound delivery company (Container shipping from China), Outbound shipping company (Royal Mail/Parcel Force), Customers

What does the organisation want to achieve in regards to their inventory management (Improved forecasting, cost reduction, improved customer satisfaction, optimised stock levels etc)

Automated perpetual inventory system
Improved customer service
Improved forecasting
Improved accuracy of inventory data avoiding discrepancies

Figure 28 Completed Inventory Management Context Capture Tool

Figure 28 and the detailed documentation for the tool in Appendix 2 present the current state of IMS and its challenges at Eco Clean. Some of the key challenges faced are human errors occurring in all workflows, supplier issues with sending incorrect inventory, poor storage of inventory as there are no set locations for organisation leading to regularly occurring instances of misplacements and mix-ups of inventory products in similarity and inaccurate forecasting and replenishment of inventory causing delayed orders. These challenges result in inaccurate inventory level data causing monetary losses of around £22,000 and a high discrepancy rate due to the inaccuracies.

6.3.2 Stage 2: Apply Inventory Management System Maturity Model (IMSMM)

This section explores the application of the Inventory Management System Maturity Model (IMSMM), as developed in Chapter 5, to Eco Clean. Through applying the IMSMM, Eco Clean's overall maturity level percentage will be calculated using the 'Overall Maturity Index' (OMI) formula, also developed in Chapter 5.

6.3.2.1 Conduct Maturity Assessment Using IMSMM

To implement stage 2 of the framework at Eco-Clean, the IMSMM in Table 24 from Chapter 5 was completed with the inventory manager. This is shown by placing a tick in the boxes in Figure 34. The yellow-coloured boxes with a tick symbol indicate what is currently implemented, leaving the boxes in red indicating what is not already implemented. The assessment focuses on what the organisation has in place regarding their IMS to provide an understanding of across which areas of the IMSMM the potential for improvements lies. The colouring of the boxes helps create a visualisation showing the colour spread of how the IMS is skewed, indicating areas that require more significant attention.

Table 34 Testing Maturity Model with Eco Clean

	Scope of Operations: IMS Activities – Receiving, Tracking, Replenishment, Location management, Shipping					
Socio-technical elements of IMS	1	2	3	4	5	6
	Data Capture Accuracy	**Maintain Data Accuracy**	**Verify Data Accuracy**	**Improve Location Data Accuracy**	**Improve Forecasting Data Accuracy**	**Improve replenishment data accuracy**
	Outcome: Accurate Transactions	Outcome: Minimal Lost/Misplaced Inventory	Outcome: Accurate Inventory Levels	Outcome: Effective Inventory Storage	Outcome: Accurate Forecasting	Outcome: Efficient Inventory Level Maintained
	(Transactions covering receiving to shipping inventory are accurate)	*(Instances of lost/misplaced inventory are minimal)*	*(Inventory levels match both on a documented/system and physical level)*	*(Inventory has SKUs & is being stored effectively i.e. locations/zones)*	*(Forecasting of inventory is done accurately with accurate inventory level data)*	*(Inventory levels are efficient to ensure instances of stock-outs do not occur)*
	Please ✓all that apply	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*
Organisation	8.1%	*10.8%*	*16.2%*	*10.8%*	*0%*	*5.4%*
People	16.6%	*16.6%*	*16.6%*	*16.6%*	*0%*	*16.6%*
Process	0%	*0%*	*0%*	*0%*	*0%*	*0%*
Technology	3.1%	*3.1%*	*6.3%*	*3.1%*	*0%*	*3.1%*
Total Maturity Level Percentage Across All OPPT Areas	**28% Out of 100%**	**31% Out of 100%**	**39% Out of 100%**	**31% Out of 100%**	**0% Out of 100%**	**25% Out of 100%**
Total Overall Maturity Percentage – 31%						

	Socio-technical elements of IMS	1	2	3	4	5	6
Organisational	CSF: Policies	Inventory inspection (Quality checking on arrival, shipping and movement of inventory)	Correct & update inventory levels both on documented / system and physical level	Inventory Auditing (monthly / annual cycle count)	Stock keeping unit (SKU) assignment & Storage (locations, zones, class based, randomised)	Accurate forecasting practices	Replenishment policy: continuous review /periodic review/JIT/EOQ
	Action: Policy Defined			✓			
	Action: Policy Implemented			✓			
	Action: Policy Followed			✓			
	CSF: Sufficient Resource						
	Action: Allocate resources to implement policy/processes		✓	✓	✓		✓
	CSF: Sufficient Budget						
	Action: Allocate the budget to implement technology	✓	✓	✓	✓		✓
	CSF: Staff Trained						
	Action: Manual Handbook of Policy and SOPs						
	Action: Induction Training	✓	✓		✓		
	CSF: Staff Competency						
	Action: Induction training on following processes/ using technology/system	✓	✓	✓	✓		✓

	Action: Monthly/Annual training renewal in following SOPs						
	Total %	**8.1%**	**10.8%**	**16.2%**	**10.8%**	**0%**	**5.4%**

Socio-technical elements of IMS		1	2	3	4	5	6
People	CSF: Staff have satisfactory Knowledge/Awareness of importance						
	Action: Read the policies (marked on system- user credentials/ visually checked in person)	✓	✓	✓	✓		✓
	CSF: Staff display Appropriate Behaviour (Avoiding Human Error)						
	Action: Series of Mock errors to test staff	✓	✓	✓	✓		✓
	CSF: Staff communicate effectively						
	Action: Schedule scenario-based training to test communication skills						
	Total %	**16.6%**	**16.6%**	**16.6%**	**16.6%**	**0%**	**16.6%**

Socio-technical elements of IMS		1	2	3	4	5	6
Process	CSF: Standard operating procedure	Standard Operating Procedure defined: Document movement of inventory from inbound to outbound. When inventory is received and shipped, it is to be inspected thoroughly to verify what has been received so that it can be updated correctly on both documented/system and physical level. Detail on how to rectify an inaccurately recorded transaction	Standard Operating Procedure defined for actioning instances where inventory being lost/misplaced is identified. Once located it is processed and placed back in the correct place and if not found it is also updating inventory levels to reflect the differences both documented/system/physical level.	Standard Operating Procedure defined: Conducting monthly and annual cycle counts of inventory ensuring levels are consistently updated reflecting the same on both documented/system /physical level. Set dates and team members are planned to initiate inventory audit across all held inventory. Detail on how to rectify instance of inaccurate inventory levels found by investigation	Standard Operating Procedure defined: Inventory is assigned unique SKUS, once inventory is received, it is processed and stored in correct locations and when moving inventory around it is stored correctly and updated both physical and documented/system level. Detail on how to rectify instance of mis-managed inventory not stored effectively	Standard Operating Procedure defined: review inventory reports, sales data and inventory levels to understand trends in data determining forecasts on inventory based on different variables aiding in decision making avoiding stock-outs. Detail on how to rectify inaccurate forecasts conducted	Standard Operating Procedure defined: From periodic/continuous reviewing inventory, following replenishment and placing a re-order point, order quantity for inventory when needed to maintain efficient inventory levels avoiding stock-out. Detail on how to rectify errors when stock-outs occur to minimise damage
	Standard Operating Procedures (SOP) Documented						
	Standard Operating Procedures (SOP) Implemented						

	Standard Operating Procedures (SOP) Followed						
	Action: Schedule silent observations to inspect staff on following SOPs in place						
	CSF: Processes integrated and aligned with technology/system in place						
	Action: Processes within SOP are regularly assessed, updated, maintained and signed off monthly						
	Total %	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**

Socio-technical elements of IMS		1	2	3	4	5	6
Technology	Technology Adopted: NONE Manual (Paper)	✓			✓		
	Technology Adopted: Spreadsheet IMS		✓	✓			
	Technology Adopted: Automated IMS						
	Technology Adopted: Integrated IMS			✓			✓
	Technology Adopted: AI/AR/Robotics						
	Technology Adopted: Automated Identification Technology: Barcoding/RFID						
	CSF: Technology integrated with functions in IMS processes						
	Action: Inspect technology/system for misalignment to processes/policy/SOPs						
	CSF: Technology is performing as expected						
	Action: Performance audit of the technology/system monthly and annually						
	Total %	**3.1%**	**3.1%**	**6.3%**	**3.1%**	**0%**	**3.1%**

Looking at the colour spread across Table 34, the organisational dimension of the IMSMM across the 5 maturity levels, shows a lack of policies implemented which are core to achieving the outcomes defined at each of the maturity levels. Any documentation or handbook of policies in that aspect is also not implemented. However, the SME implements some form of staff induction training and currently has an inventory auditing policy. In relation to the people dimension of the IMSMM, staff have some knowledge and awareness of the existing workflows of the IMS due to the training documentation provided and has been read however, there are no ways to document the maintenance of the knowledge and training provided as dynamics change within the warehouse regarding inventory management. The process dimension shows that there is a severe lack of any processes or standard operating procedures for all tasks regarding inventory management, indicating a key area of improvement is urgently required. Finally, the technology dimension across the maturity levels indicates limited AIT technologies and use of automated IMS. Currently, a mix of paper-based and spreadsheet systems are mainly used to monitor and track inventory levels whilst also using a courier and e-commerce platform-supported order management system; however, this presents issues with integration and does not update inventory levels in real-time.

6.3.2.2 Refinements to Inventory Management System Maturity Model (IMSMM)

After the IMSMM was initially applied to Eco Clean, it was realised that 'Level 5—Improve forecasting data accuracy' was not required for this specific organisation. Although it is related to inventory management as accurate inventory data is required for accurate forecasting, it was not a main activity directly conducted in the warehouse environment regarding inventory. This refinement was then made to the maturity model, showing only 5 maturity levels as opposed to 6 after removing the accurate forecasting maturity level. Table 35 shows the refined maturity model used with the assessment results completed in the study. Table 35 only presents the overview calculation of the overall maturity level percentage as the model applied is the same as Table 34, just without the maturity level 5 column.

Table 35 Refined Maturity Model Used in the Study

	Scope of Operations: IMS Activities – Receiving, Tracking, Replenishment, Location management, Shipping				
Socio-technical elements of IMS	1	2	3	4	5
	Data Capture Accuracy	**Maintain Data Accuracy**	**Verify Data Accuracy**	**Improve Location Data Accuracy**	**Improve replenishment data accuracy**
	Outcome: Accurate Transactions	Outcome: Minimal Lost/Misplaced Inventory	Outcome: Accurate Inventory Levels	Outcome: Effective Inventory Storage	Outcome: Efficient Inventory Level Maintained
	(Transactions covering receiving to shipping inventory are accurate)	*(Instances of lost/misplaced inventory are minimal)*	*(Inventory levels match both on a documented/system and physical level)*	*(Inventory has SKUs & is being stored effectively i.e. locations/zones)*	*(Inventory levels are efficient to ensure instances of stock-outs do not occur)*
	Please ✓all that apply	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*
Organisation	8.1%	*10.8%*	*16.2%*	*10.8%*	*5.4%*
People	16.6%	*16.6%*	*16.6%*	*16.6%*	*16.6%*
Process	0%	*0%*	*0%*	*0%*	*0%*
Technology	3.1%	*3.1%*	*6.3%*	*3.1%*	*3.1%*
Total Maturity Level Percentage Across All OPPT Areas	**28% Out of 100%**	**31% Out of 100%**	**39% Out of 100%**	**31% Out of 100%**	**25% Out of 100%**
Total Overall Maturity Percentage – 31%					

6.3.2.3 Calculate and Assign Overall Maturity Level Percentage

Once the IMSMM table has been completed and the model has been refined to the specific case organisation, the overall maturity percentage was then calculated using the formula developed in Chapter 5, section 5.3.2.11.3.

$$Overall\ Maturity\ Level\ \% = \frac{\sum_{i=1}^{M} \sum_{j=1}^{D} P_{i,j}}{M}$$

To calculate the overall maturity, as per the formula developed, the individual maturity percentages are first calculated for each maturity level across the 4 dimensions.

6.3.2.3.1 Calculate the Maturity Percentage for Each Maturity Level

Calculating the individual maturity percentage for each maturity level across the 4 dimensions, is dependent on how many individual items across the 5 levels and 4 dimensions have been ticked in the initial maturity model assessment, completing the table. As each of the 4 dimensions was given a total of 25% weighting, the individual maturity percentage for each level across each OPPT area was given a score out of 25%. Therefore, the sum of these figures results in the total maturity percentage for that respective maturity level. After calculations, final maturity level percentages achieved for each level are shown in Table 36.

Table 36 Calculated Maturity Level Percentages Post IMSMM Application

Maturity Levels / **Dimensions**		**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Organisational	$\frac{25}{9} * n✓ =$	8.1%	10.8%	16.2%	10.8%	5.4%
People	$\frac{25}{3} * n✓ =$	16.6%	16.6%	16.6%	16.6%	16.6%
Process	$\frac{25}{5} * n✓ =$	0%	0%	0%	0%	0%
Technology	$\frac{25}{8} * n✓ =$	3.1%	3.1%	6.3%	3.1%	3.1%

Total Maturity Percentage For Each Level		28%	31%	39%	31%	25%

Table 37 present the formulas to show the individual maturity percentage calculated for each maturity level.

Table 37 Calculated Maturity Level Percentage for Each Maturity Level 1-5

Level 1 Maturity Level Percentage	$\sum_{j=1}^{4} P_{i,j} = 8.1 + 16.6 + 0 + 3.1 = 28\%$
Level 2 Maturity Level Percentage	$\sum_{j=2}^{4} P_{i,j} = 10.8 + 16.6 + 0 + 3.1 = 31\%$
Level 3 Maturity Level Percentage	$\sum_{j=3}^{4} P_{i,j} = 16.2 + 16.6 + 0 + 6.3 = 39\%$
Level 4 Maturity Level Percentage	$\sum_{j=4}^{4} P_{i,j} = 10.8 + 16.6 + 0 + 3.1 = 31\%$
Level 5 Maturity Level Percentage	$\sum_{j=5}^{4} P_{i,j} = 5.4 + 16.6 + 0 + 3.1 = 25\%$

Table 38 Final Calculated Maturity Level Percentages

Maturity Level	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Total Maturity Percentage For Each Level	28%	31%	39%	31%	25%

The final maturity level percentages calculated in Table 38 are required to calculate the overall maturity percentage.

6.3.2.3.2 Calculate the Overall Maturity Level Percentage

The formula below shows the calculation of the overall maturity level percentage through the summation of the individual maturity level percentage and dividing by number of maturity levels (5).

$$Overall\ Maturity\ Level\ \% = \frac{(18.6 + 16.6 + 0 + 3.1) + (10.8 + 16.6 + 0 + 3.1) + (16.2 + 16.6 + 0 + 6.3) + (10.8 + 16.6 + 0 + 3.1) + (5.4 + 16.6 + 0 + 3.1)}{5}$$

$$\frac{(28) + (31) + (39) + (31) + (25)}{5} = 31\%$$

The overall maturity level percentage calculated from the initial maturity assessment is 31%. The next section explains the recommended actions from the IMSMM and their implementation within Eco Clean to improve the maturity of their IMS.

6.3.3 Stage 3: State & Implement Recommended Actions

After applying stage 2, the application of the IMSMM, the recommended actions were extracted based on the initial maturity level assigned. The recommended actions are embedded within the IMSMM and selected, whereby the critical success factor items within the maturity model that the organisation has not addressed represent the recommended actions necessary for achieving full maturity, quantified as 100% across each of the 4 dimensions and 5 maturity levels. Table 24 shows Eco Clean's current IMS maturity model, with items not addressed by the organisation, coloured red. These are the recommended actions to improve IMS maturity and improve inventory data quality. The number of recommended actions presented to the organisation was vast, indicating the improvement needed in their inventory management system.

Due to the timeline of this study, only 6 months' worth of improvement data has been documented, as not all recommended actions could be implemented within this timeframe. However, many improvements have been made, showcasing improvement within the inventory management system. The overarching objective is to ensure that all critical success factors delineated in the maturity model are implemented within the organisation, facilitating the attainment of a 100% maturity level. Table 39 details the list of recommended actions for improvement and their implementation at Eco Clean.

Table 39 Recommended Actions Stated and Implemented

Policies	- Inventory Inspection - (Quality checking on arrival, shipping and movement of inventory) - Correct and Update – (Correcting inventory levels both on the system and physical level) - Inventory Auditing - (monthly/annual cycle count) - Stock Keeping Unit (SKU) assignment & Storage Layout- (Locations/ Zones) - Replenishment Policy – Continuous Review
Manual Handbook of Policies/SOPs	- Manual handbook of policies and standard operating procedures created
Standard Operating Procedure	- Document movement of inventory from inbound to outbound - Actioning instances where inventory lost/misplaced is identified (Correct and Update) - Conducting monthly and annual cycle counts of inventory - Assign SKUs and process inventory to store in the correct locations - Follow replenishment policy and identify re-order points for maintaining efficient inventory levels, avoiding stock-outs
Processes within SOPs are regularly assessed, updated, maintained and signed off	- All processes that are within the standard operating procedures are regularly assessed, updated, maintained to ensure that they are working efficiently
Automated IMS implemented – Bespoke Order Management System	- Automated system to manage and fulfil orders, clearly see dispatch notes to know what items needed packing for larger orders to avoid packing errors impacting inventory data, easy user interface and experience (UI/UX), inventory reporting feature embedded automatically calculating inventory quantities shipped across all products and reporting.
Advanced Spreadsheets Developed	- **Improved Inventory Count Spreadsheet –** Interactive Spreadsheet with added formulas to reduce human error in calculation, better organisation and used monthly for auditing purposes. - **Daily Dispatch Inventory Data Tracker (For inventory level data verification)** To monitor dispatching orders and fulfilled inventory quantities daily and input into a spreadsheet to verify inventory levels on both physical and system levels.

	- **Overstock location management spreadsheet –** Tracking stock moves from storage units where overstock is stored in another location separate from the warehouse**.** Tracked and updated inventory data levels when moving stock from external storage units to internal warehouse, allowing updated figures to be used for monthly auditing. - **Deliveries from US/China –** Recording purchase orders (PO), matching PO to goods received, inspecting goods on arrival, documenting discrepancies in units sent, damaged, etc. A spreadsheet to document all incoming deliveries from suppliers and organise them according to purchase orders, SKUs and quantities. - Improved communication with suppliers regarding state of deliveries received, shipments are now sent with no errors, stock is organised and PO's labelled for traceability. - **Warehouse floor plan –** A new warehouse floor plan showing locations/zones for each type of product developed to ensure inventory is managed and stored effectively.
Performance audit of the system/ spreadsheets in place to ensure they are performing well	- Some spreadsheets already existing on a very basic level have been updated and increased in advanced functionality, such as formulas to minimise human calculation etc Performance audits are carried out on all Spreadsheets and automated system in place to ensure that it is performing well and providing accurate inventory data.

6.4 Results

Table 40 presents the re-application of the IMSMM table completed, showcasing the impact of implementing the recommended actions resulting in a new, improved maturity level. This section explains the results achieved from the testing of the framework by implementing the IMCCT and the IMSMM. Post implementation of the recommended actions as explained in Section 6.3.3, the IMSMM was reapplied to the case organisation to determine whether the implementation of the recommended actions had changed the IMS maturity level percentage.

6.4.1 Post Implementation of Recommended Actions & Reapplying the IMSMM to Present Improved Maturity Level

Table 40 Re-Application of IMSMM Showing Improved Overall Maturity Level Percentage

	Scope of Operations: IMS Activities – Receiving, Tracking, Replenishment, Location management, Shipping				
Socio-technical elements of IMS	1	2	3	4	5
	Data Capture Accuracy	**Maintain Data Accuracy**	**Verify Data Accuracy**	**Improve Location Data Accuracy**	**Improve replenishment data accuracy**
	Outcome: Accurate Transactions	Outcome: Minimal Lost/Misplaced Inventory	Outcome: Accurate Inventory Levels	Outcome: Effective Inventory Storage	Outcome: Efficient Inventory Level Maintained
	(Transactions covering receiving to shipping inventory are accurate)	*(Instances of lost/misplaced inventory are minimal)*	*(Inventory levels match both on a documented/system and physical level)*	*(Inventory has SKUs & is being stored effectively i.e. locations/zones)*	*(Inventory levels are efficient to ensure instances of stock-outs do not occur)*
	Please ✓all that apply	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*	*Please ✓all that apply*
Organisation	19.4%	*22.2%*	*22.2%*	*22.2%*	*22.2%*
People	16.6%	*16.6%*	*16.6%*	*16.6%*	*16.6%*
Process	20%	20%	*0%*	*0%*	20%
Technology	9.3%	*6.3%*	*9.3%*	*6.3%*	*6.3%*
Total Maturity Level Percentage Across All OPPT Areas	**65% Out of 100%**	**65% Out of 100%**	**68% Out of 100%**	**65% Out of 100%**	**65% Out of 100%**
Total Overall Maturity Percentage – 66%					

Socio-technical elements of IMS		1	2	3	4	5
Organisational	CSF: Policies	Inventory inspection (Quality checking on arrival, shipping and movement of inventory)	Correct & update inventory levels both on documented / system and physical level	Inventory Auditing (monthly / annual cycle count)	Stock keeping unit (SKU) assignment & Storage (locations, zones, class based, randomised)	Replenishment policy: continuous review /periodic review/JIT/EOQ
	Action: Policy Defined	✓	✓	✓	✓	✓
	Action: Policy Implemented	✓	✓	✓	✓	✓
	Action: Policy Followed	✓	✓	✓	✓	✓
	CSF: Sufficient Resource					
	Action: Allocate resources to implement policy/processes		✓	✓	✓	✓
	CSF: Sufficient Budget					
	Action: Allocate the budget to implement technology	✓	✓	✓	✓	✓
	CSF: Staff Trained					
	Action: Manual Handbook of Policy and SOPs	✓	✓	✓	✓	✓
	Action: Induction Training	✓	✓	✓	✓	✓
	CSF: Staff Competency					
	Action: Induction training on following processes/ using technology/system	✓	✓	✓	✓	✓
	Action: Monthly/Annual training renewal in following SOPs					
	Total %	**19.4%**	**22.2%**	**22.2%**	**22.2%**	**22.2%**

Socio-technical elements of IMS		1	2	3	4	5
People	CSF: Staff have satisfactory Knowledge/Awareness of importance					
	Action: Read the policies (marked on system- user credentials/ visually checked in person)	✓	✓	✓	✓	✓
	CSF: Staff display Appropriate Behaviour (Avoiding Human Error)					
	Action: Series of Mock errors to test staff	✓	✓	✓	✓	✓
	CSF: Staff communicate effectively					
	Action: Schedule scenario-based training to test communication skills					
	Total %	**16.6%**	**16.6%**	**16.6%**	**16.6%**	**16.6%**

Socio-technical elements of IMS		1	2	3	4	5
Process	CSF: Standard operating procedure	Standard Operating Procedure defined: Document movement of inventory from inbound to outbound. When inventory is received and shipped, it is to be inspected thoroughly to verify what has been received so that it can be updated correctly on both documented/system and physical level. Detail on how to rectify an inaccurately recorded transaction	Standard Operating Procedure defined for actioning instances where inventory being lost/misplaced is identified. Once located it is processed and placed back in the correct place and if not found it is also updating inventory levels to reflect the differences both documented/system/physical level.	Standard Operating Procedure defined: Conducting monthly and annual cycle counts of inventory ensuring levels are consistently updated reflecting the same on both documented/system /physical level. Set dates and team members are planned to initiate inventory audit across all held inventory. Detail on how to rectify instance of inaccurate inventory levels found by investigation	Standard Operating Procedure defined: Inventory is assigned unique SKUS, once inventory is received, it is processed and stored in correct locations and when moving inventory around it is stored correctly and updated both physical and documented/system level. Detail on how to rectify instance of mis-managed inventory not stored effectively	Standard Operating Procedure defined: From periodic/continuous reviewing inventory, following replenishment and placing a re-order point, order quantity for inventory when needed to maintain efficient inventory levels avoiding stock-out. Detail on how to rectify errors when stock-outs occur to minimise damage
	Standard Operating Procedures (SOP) Documented	✓	✓	✓	✓	✓
	Standard Operating Procedures (SOP) Implemented	✓	✓	✓	✓	✓
	Standard Operating Procedures (SOP) Followed	✓	✓	✓	✓	✓
	Action: Schedule silent observations to inspect staff on following SOPs in place					

	CSF: Processes integrated and aligned with technology/system in place					
	Action: Processes within SOP are regularly assessed, updated, maintained and signed off monthly	✓	✓	✓	✓	✓
	Total %	**20%**	**20%**	**20%**	**20%**	**20%**

Socio-technical elements of IMS		1	2	3	4	5
Technology	Technology Adopted: NONE Manual (Paper)	✓			✓	
	Technology Adopted: Spreadsheet IMS	✓	✓	✓	✓	✓
	Technology Adopted: Automated IMS			✓		
	Technology Adopted: Integrated IMS			✓		✓
	Technology Adopted: AI/AR/Robotics					
	Technology Adopted: Automated Identification Technology: Barcoding/RFID					
	CSF: Technology integrated with functions in IMS processes					
	Action: Inspect technology/system for misalignment to processes/policy/SOPs					
	CSF: Technology is performing as expected					
	Action: Performance audit of the technology/system monthly and annually	✓	✓	✓	✓	✓
	Total %	**9.3%**	**6.3%**	**9.3%**	**6.3%**	**6.3%**

Post implementation of the recommended actions, it can be seen that specific CSFs as recommended actions have been implemented through showing the colour spread indicating green as the actions now implemented. Policies, processes and standard operating procedures were identified as being a key problematic area in the initial maturity assessment, that needed to be addressed in the recommendation actions. Policies, processes and standard operating procedures have now been put into place at Eco Clean and have significantly impacted the quality of inventory data accuracy.

6.4.1.1 Calculate the Improved Overall Maturity Level Percentage

Once the recommended actions have been implemented, the re-application of the IMSMM is conducted to re-assess the maturity of the case organisation showcasing the impact of improvements made resulting in an improved overall maturity level percentage. The re-application of the IMSMM follows the same steps as explained in the initial maturity assessment in Section 6.3.2.

6.4.1.1.1 Calculate the Improved Maturity Percentage for Each Maturity Level

To calculate the overall maturity level percentage, firstly, the individual maturity level percentages need to be calculated as presented in Table 41.

Table 41 Calculated Maturity Level Percentages Post IMSMM Application

Maturity Levels / **Dimensions**	**Formula**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
Organisational	$\frac{25}{9} * n\checkmark =$	19.4%	22.2%	22.2%	22.2%	22.2%
People	$\frac{25}{3} * n\checkmark =$	16.6%	16.6%	16.6%	16.6%	16.6%
Process	$\frac{25}{5} * n\checkmark =$	20%	20%	20%	20%	20%
Technology	$\frac{25}{8} * n\checkmark =$	9.3%	6.3%	9.3%	6.3%	6.3%
Total Maturity Percentage for Each Level		**65%**	**65%**	**68%**	**65%**	**65%**

Table 42 shows the individual maturity percentage calculated for each maturity level.

Table 42 Calculated Improved Maturity Level Percentage for Each Maturity Level 1-5

Level 1 Improved Maturity Percentage	$\sum_{j=1}^{4} P_{i,j} = 19.4 + 16.6 + 20 + 9.3 = 65\%$
Level 2 Improved Maturity Percentage	$\sum_{j=2}^{4} P_{i,j} = 22.2 + 16.6 + 20 + 6.3 = 65\%$
Level 3 Improved Maturity Percentage	$\sum_{j=3}^{4} P_{i,j} = 22.2 + 16.6 + 20 + 9.3 = 68\%$
Level 4 Improved Maturity Percentage	$\sum_{j=4}^{4} P_{i,j} = 22.2 + 16.6 + 20 + 6.3 = 65\%$
Level 5 Improved Maturity Percentage	$\sum_{j=5}^{4} P_{i,j} = 22.2 + 16.6 + 20 + 6.3 = 65\%$

Table 43 Final Improved Maturity Percentages for Each Maturity Level

Maturity Level	Level 1	Level 2	Level 3	Level 4	Level 5
Total Maturity Percentage for Each Level	**65%**	**65%**	**68%**	**65%**	**65%**

The final maturity level percentages calculated in Table 43 for each maturity level are required to calculate the overall improved maturity level percentage.

6.4.1.1.2 Calculate the Overall Improved Maturity Level Percentage

This formula calculates the overall improved maturity level percentage

$$\mathit{Overall\ Maturity\ Level\ \%} = \frac{(19.4 + 16.6 + 20 + 9.3) + (22.2 + 16.6 + 20 + 6.3) + (22.2 + 16.6 + 20 + 9.3) + (22.2 + 16.6 + 20 + 6.3) + (22.2 + 16.6 + 20 + 6.3)}{5}$$

$$\frac{(65) + (65) + (68) + (65) + (65)}{5} = 66\%$$

After implementing the recommended actions and re-applying the IMSMM, the overall improved maturity level percentage is 66%.

6.4.2 Maturity Improvement Percentage

To measure the quality of improvement in the maturity level, the percentage improvement can be calculated as a basic metric representing the relative increase from the initial overall maturity level to the improved overall maturity level. The equation shows a percentage improvement rate of 112.90% showing that the maturity level has more than doubled from its starting maturity level at 31%, indicating a substantial improvement in the SMEs inventory management system.

$$Maturity\ Improvement\ \% = \frac{Improved\ Maturity\ Level - Initial\ Maturity\ Level}{Initial\ Maturity\ Level} * 100$$

Initial Maturity Level = 31%

Improved Maturity Level = 66%

$$Maturity\ Improvement\ \% = \left(\frac{66 - 31}{31} * 100\right) = 112.90\%$$

6.4.3 Discrepancy Rate Improvement Percentage

Figure 29 presents the inventory data discrepancy report from Eco Clean. This details the inventory data for all 11 products from January 2024 when the maturity model assessment took place, to June 2024 when the maturity model was re-applied after implementing the recommended actions over 6 month period. It further explains the inventory level data for the products on both accounted for on system and accounted for on hand (system and physical level), clearly defining the discrepancy in number of units. The data shows that in month January the total discrepancy percentage of inventory data was 10.21% with a monetary value attached of £22,762.87. This data shows, due to the discrepancies in inventory data, the company was incurring a loss of just over £22,000.

Post implementing the recommended actions over the 6 months, the data for June 2024 shows a substantial improvement, reducing the discrepancy percentage to 0.53% and reducing the monetary loss to £525.35 solving the original problems identified in the IMCCT. This shows measurable impact, and improvements have been made on the quality of inventory data. In this instance where Eco Clean is still losing £525.35 over the 6 months is due to how human errors are always occurring, maturing IMS helps minimise these errors and helps to detect and correct these errors more quickly.

Month	Product 1	Product 2	Product 3	Product 4	Product 5	Product 6	Product 7	Product 8	Product 9	Product 10	Product 11		
January													
ACCOUNTED Onhand - System	65,789	13,559	80,301	64,058	3,494	3,100	1,191	724	500	1,000	896		
ACTUAL Count - Physical	56,753	11,311	73,590	62,682	3,419	3,054	1,320	637	439	672	896		
Unit Discrepancy	-9,036	-2,248	-6,711	-1,376	-75	-46	129	-87	-61	-328	0		
% Discrepancy	14%	17%	8%	2%	2%	1%	-11%	12%	12%	33%	0%	10.21%	Average %
£ Monetary Value	-£9,939.60	-£2,472.80	-£6,375.45	-£1,307.20	-£138.75	-£39.56	£335.40	-£226.20	-£114.07	-£1,813.84	£0.00	£22,762.87	Total £
June													
ACCOUNTED Onhand - System	21,763	4,244	232,076	104,848	2,970	2,507	868	989	433	667	874		
ACTUAL Count - Physical	21,713	4,086	232,219	104,973	2,967	2,507	855	988	433	667	874		
Unit Discrepancy	-50	-158	143	125	-3	0	-13	-1	0	0	0		
% Discrepancy	0.23%	3.72%	-0.06%	-0.12%	0.10%	0.00%	1.50%	0.10%	0.00%	0.00%	0.00%	0.53%	Average %
£ Monetary Value	-£55.00	-£173.80	£135.85	£118.75	-£5.55	£0.00	-£33.80	-£2.60	£0.00	£0.00	£0.00	£525.35	Total £

Figure 29 Inventory Data Discrepancy Report

This equation calculates the rate of improvement regarding the discrepancy rate. An improvement percentage of 94.81% indicates a significant reduction in the rate of discrepancies in inventory data, thus improving inventory data quality.

$$Improvement\ Rate\ \% = \frac{Initial\ Discrepancy\ Rate - Final\ Discrepancy\ Rate}{Initial\ Discrepancy\ Rate} * 100$$

Initial Discrepancy rate = 10.21%

Final Discrepancy rate = 0.53%

$$Improvement\ Rate\ \% = \left(\frac{10.21 - 0.53}{10.21} * 100\right) = 94.81\%$$

6.4.4 Impact on Data Quality Measures

This section presents the measurement of the impact on data quality measures using impact levels: ***Low, Moderate*** and ***High*** impact, to show how it influences the overall maturity level percentage. The impact levels associated with each of the data quality measures as outlined in Section 5.4.7, Chapter 5, was used to conduct the data quality impact. To discuss the impact on data quality measures, the curated list of selected data quality measures from Chapter 2 in Section 2.7.5 is used, along with the table outlining the impact levels associated with each data quality measure in Figure 33, Chapter 5.

Table 44 Impact Levels Assigned to Each Data Quality Measure Pre and Post Maturity Assessment

Data Quality Measure	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Calculate Individual Percentage Improvement
Accuracy	Low	1	High	3	2	$Accuracy = \frac{3-1}{3-1} * 100 = 100\%$
Timeliness	Moderate	2	Moderate	2	0	$Timeliness = \frac{2-2}{3-1} * 100 = 0\%$
Reliability	Moderate	2	High	3	1	$Reliability = \frac{3-2}{3-1} * 100 = 50\%$
Traceability	Low	1	High	3	2	$Traceability = \frac{3-1}{3-1} * 100 = 100\%$
Completeness	Low	1	High	3	2	$Completeness = \frac{3-1}{3-1} * 100 = 100\%$
Relevancy	High	3	High	3	0	$Relevancy = \frac{3-3}{3-1} * 100 = 0\%$
Value-added	Moderate	2	Moderate	2	0	$Value\ Added = \frac{2-2}{3-1} * 100 = 0\%$
Ease-of-understanding	Moderate	2	Moderate	2	0	$Ease\ of\ Understanding = \frac{2-2}{3-1} * 100 = 0\%$

Integration	Low	1	High	3	2	$Integration = \frac{3-1}{3-1} * 100 = 100\%$
Clarity	Low	1	Moderate	2	1	$Clarity = \frac{2-1}{3-1} * 100 = 50\%$
Efficiency	Moderate	2	High	3	1	$Effciency = \frac{3-2}{3-1} * 100 = 50\%$
Ease of Use	Low	1	High	3	2	$Ease\ of\ Use = \frac{3-1}{3-1} * 100 = 100\%$
Validity	Low	1	High	3	2	$Validity = \frac{3-1}{3-1} * 100 = 100\%$
Consistency	Moderate	2	High	3	1	$Consistency = \frac{3-2}{3-1} * 100 = 50\%$
Usability	Moderate	2	High	3	1	$Usability = \frac{3-2}{3-1} * 100 = 50\%$

Table 44 outlines the data quality measures as the scoring assigned to each data quality measure from before conducting the maturity assessment to after conducting the maturity assessment and implementing the recommended action. According to the impact levels, low, moderate and high, table 44 shows the impact improvement made on each data quality measure, showing where improvements have been made. Following the formula as outlined in Section 5.4.7.1 in Chapter 5, the impact improvement of each data quality measure is presented in the last column in Table 44 where some data quality measures have been improved, whilst some have remained the same.

6.4.4.1 Calculate Data Quality Improvement Percentage

This expression presents the overall data quality improvement percentage using the formula to add all data quality improvement percentages together and divide by the number of data quality measures formula:

$$Overall\ Data\ Quality\ Improvement\ \%$$
$$= \frac{100\% + 50\% + 100\% + 100\% + 100\% + 50\% + 50\% + 100\% + 100\% + 50\% + 50\%}{15} * 100$$
$$= \mathbf{56.6\%}$$

This shows that there was a **56.6 % improvement** on average across the 15 data quality measures after the maturity assessment and implementation of recommended actions.

6.4.2.2 Improvement Impact on Each Maturity Level Against Associated Data Quality Measures

This section outlines the improvement impact of the specific data quality measures associated with each of the maturity levels, as explained in Chapter 5 in Section 5.4 detailing the relationship between the data quality measures and the corresponding maturity levels. The improvement impact of the data quality measures associated with the maturity levels has been explained against the implementation of the recommended actions at Eco Clean after the maturity assessment, to show what data has been measured for improvement and how it has been improved.

Level 1- Data Capture Accuracy

Inventory Data Type: E.g. Incoming supplier deliveries and processing inventory being received and stored in the warehouse.

Table 45 Level 1 Data Quality Improvement Impact

Data Quality Measure:	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Individual Percentage Improvement
Accuracy	Low	1	High	3	2	100%
Timeliness	Moderate	2	Moderate	2	0	0%
Completeness	Low	1	High	3	2	100%
Ease-of-Understanding	Moderate	2	Moderate	2	0	0%
Improvement Impact on Maturity Level 1 (Based on Recommended Actions Implemented)	- The inspection policy regarding quality checking the inventories on arrival and movement of this inventory ensures accuracy in units processed into existing inventory levels. - The SOP for receiving inbound shipments implemented ensures that inventories received from suppliers are checked on arrival as well as, inspected thoroughly to process the correct quantities, ensuring that deliveries are correctly processed, initially capturing the data regarding inbound inventory accurately. - Improved communication with the suppliers now ensures inventory data regarding the inbound inventories and shipments from suppliers is now complete and easy to understand, where data is not missing, is sent in a timely manner, reduced to no errors from suppliers, stock is sent organised with box numbers in shipment containers for easier and less complicated off-loading and purchase orders are all labelled giving complete data to process.					

Level 2- Maintain Data Accuracy

Inventory Data Type: Maintaining inventory level data, by reducing instances of lost/misplaced inventory and rectifying these instances to reflect correct data.

Table 46 Level 2 Data Quality Improvement Impact

Data Quality Measure	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Individual Percentage Improvement
Consistency	Moderate	2	High	3	1	50%
Reliability	Moderate	2	High	3	1	50%
Validity	Low	1	High	3	2	100%
Traceability	Low	1	High	3	2	100%
Usability	Moderate	2	High	3	1	50%
Improvement Impact on Maturity Level 2	- The policy implemented regarding correcting and updating the inventory levels in instances of lost/misplaced stock has enabled the accuracy of inventory level data to be maintained, reducing the discrepancies between system and physical levels of inventory. - The SOP implemented regarding maintaining the accuracy of data, ensures that inventory items are placed back in the correct place improving traceability, and if not found, this is then reflected between the system and physical inventory level data ensuring accuracy is maintained.					

	- It also increases the reliability and validity of the inventory data in return as inventory level data can be trusted and reliably used in auditing and inventory reporting for finances.

Level 3- Verify Data Accuracy

Inventory Data Type: Verifying inventory level data is accurate through auditing.

Table 47 Level 3 Data Quality Improvement Impact

Data Quality Measure:	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Individual Percentage Improvement
Reliability	Moderate	2	High	3	1	50%
Validity	Low	1	High	3	2	100%
Traceability	Low	1	High	3	2	100%
Relevancy	High	3	High	3	0	0%
Ease-of-Use	Low	1	High	3	2	100%
Improvement Impact on Maturity Level 3	- The SOP implemented regarding conducting monthly and annual inventory cycle counts ensures that inventory levels are constantly verified and consistently updated, reflecting the accurate inventory levels on both system and physical levels. Cycle counts are done regularly at the end of every month on the date set by the manager to ensure consistency.					

	- The improved inventory count spreadsheet contains added formulas to reduce human error in calculation, increasing the reliability, validity, and relevancy of the data. The improved spreadsheet is now more organised and easier for staff to use. - The daily dispatch inventory tracker spreadsheet was specifically implemented to monitor dispatching orders and fulfilled inventory quantities daily so this could be matched with the automated system implemented to manage and fulfil orders, enabling the verification of inventory level accuracy.

Level 4- Improve Location Data Accuracy

Inventory Data Type: Improve Inventory data location and storage to ensure inventory is stored adequately.

Table 48 Level 4 Data Quality Improvement Impact

Data Quality Measure:	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Individual Percentage Improvement
Accuracy	Low	1	High	3	2	100%
Integration	Low	1	High	3	2	100%
Clarity	Low	1	Moderate	2	1	50%
Efficiency	Moderate	2	High	3	1	50%

Value-Added	Moderate	2	Moderate	2	0	0%
Traceability	Low	1	High	3	2	100%
Improvement Impact on Maturity Level 4	- The policy and SOP regarding effectively storing inventory are implemented and ensure that stock keeping units (SKUS) are assigned to products so that they can easily be traced, located and inventory data is accurate for each product. - A warehouse floor plan is implemented, showing specific zones and locations that have been assigned to products, improving inventory location data. When received, inventory is processed and placed efficiently in the correct assigned locations for each product in the shipment. This ensures value-added location data as it is now organised and can be used to optimise order-picking processes in return. - Due to the large amount of inventory holding exceeding the warehouse capacity, additional inventory is held in external storage units in separate premises. The overstock location management spreadsheet developed enables improved traceability of the inventory and ensures accurate inventory levels and seamless transfer of inventory when required at warehouse premises for fulfilment. This improves the integration between the inventory levels at the external storage units and the inventory count spreadsheet for auditing purposes, verifying inventory data accuracy.					

Level 5- Improve Replenishment Data Accuracy

Inventory Data Type: Improve Replenishment level data to ensure reduced/low instances of stock-outs

Table 49 Level 5 Data Quality Improvement Impact

Data Quality Measure:	Impact Level	Original Measure (Pre- Maturity Assessment)	Impact Level	Impact Score Final (Post Maturity Assessment)	Impact Improvement	Individual Percentage Improvement
Accuracy	Low	1	High	3	2	100%
Timeliness	Moderate	2	Moderate	2	0	0%
Relevancy	High	3	High	3	0	0%
Completeness	Low	1	High	3	2	100%
Efficiency	Moderate	2	High	3	1	50%
Improvement Impact on Maturity Level 5	- The policy and SOP implemented to ensure that replenishment data accuracy is improved ensured that stock-outs are minimised by consistently having inventory available to meet demand. - Periodically reviewing the inventory levels ensures that at least 90 days of inventory is available before triggering a replenishment order for a product. This emphasises that the timeliness and completeness of this review for replenishment is important as inventory can only be ordered considering the supplier lead times and when the next batch order is being placed with the supplier. Improving the replenishment data accuracy ensures efficient replenishment of inventory avoiding instances of stock-outs.					

6.5 Critical Review of the Framework

The framework developed and applied within this chapter consists of three stages: i) Inventory Management Context Capture Tool, ii) Inventory Management System Maturity Model and iii) State and implement recommended actions. The overall maturity index (OMI) developed to calculate the overall maturity level percentage to be assigned to the case organisation, provides a quantifiable measure for evaluating the maturity of inventory management systems in SMEs. However, it is important to critically evaluate its strengths, limitations and implications for both research and practice.

6.5.1 Strengths

The key strengths of the framework are outlined below:

- The maturity model stage of the framework integrates 4 socio-technical dimensions (Organisation, People, Process and Technology) and 5 maturity levels. This links back to fulfilling the research gap as key authors Vries (2005,2007,2013, 2020), Muchaendepi et al. (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) state that a holistic STS approach is needed. This framework fulfils the research gap as the structure of the model accounts for systemic interdependencies between organisation, people, process and technology, further strengthening the model's theoretical underpinnings.
- The diagnostic and prescriptive utility of the maturity model is particularly strong as it not only identifies maturity but also highlights specific recommended actionable improvements being a practical model.
- The maturity model includes a key feature: the quantitative overall maturity index formula developed. This formula encompasses a weighted summation and overall mean-based calculation to measure maturity, ensuring quantitative rigour.
- The weighting of each of the dimensions across the maturity levels is a strength in the model, as it is designed to be adaptable, allowing customisation based on specific industry or organisational needs, enhancing its practical relevance.

6.5.2 Limitations

The core limitations of the framework are outlined below:

- The maturity model consists of too many calculations, including the overall maturity index formula, which may seem complex, and risk being misapplied. This can lead to inaccurate application of the framework and inaccurate results.
- There is limited guidance provided to help others use the framework and conduct the calculations of maturity.
- The focus on quantitative measures and their impact can overlook the qualitative insights to be brought in from the incorporation of socio-technical dimensions.
- The framework states recommended actions post-maturity assessment. However, there are no supporting guidelines or action plans to outline how the improvements can be implemented, which detail the cost involved and which recommended actions to start first.
- The framework requires a lot of data to be manually collected from the organisation, which can include potential interpretation bias.

This critical review of the framework underscores the importance of understanding strengths and limitations for continuous refinements and validation to ensure the model's relevance and impact in diverse contexts.

6.6 Discussion of Results

Eco Clean's inventory management system has been assessed and improved through the implementation of the proposed framework. The inventory discrepancy data from the case organisation is presented in Figure 29 from January 2024 to June 2024. This data has been calculated to show the discrepancy as both a percentage and a monetary value. After applying the maturity model assessment, the overall maturity level initially assigned to Eco Clean was 31%. Once the recommended actions were given and implemented over the course of 6 months, the re-assessment of maturity resulted in the overall maturity level being improved to an outstanding 66%. These results are presented in further detail showing the maturity percentage rate improvement as 112.90% presented in Section 6.4.2. In addition, this maturity improvement has also reduced the discrepancy rate percentage from 10.31% in January to 0.53% in June with a monetary value of £525.35, showing a substantial cost saving of £22,237.52 for Eco Clean in the period of 6 months. Overall, this shows significant improvement made in the organisation in improving both the inventory data quality and inventory management system performance overall.

The specific recommended action under the Technology dimension—Order Management System with embedded inventory module—initially cost the organisation around £7,000+. However, as the potential impact of this technology was acknowledged, this was quickly invested in and completed, enabling the improvement of inventory data accuracy alongside the other recommended actions implemented across the OPPT dimensions. The return on investment can be seen in the reduction in discrepancy rate and improved cost savings presented in Section 6.4.3.

The curated list of data quality measures used in this research as outlined in Chapter 2, literature review and referred to in this chapter in Section 6.4.4, have been reviewed in terms of their impact before and after the maturity assessment and implementation of recommended actions. After calculating the overall data quality improvement percentage across all 15 data quality measures, it is noted that the data quality improvement percentage is **56.6%** showing a substantial improvement of inventory data quality.

At first the process seemed confusing to the participant as it was new to them. But, as the maturity assessment was explained and support was provided to apply the maturity assessment, it provided further clarity and the value of the tool was recognised. Implementing the recommended actions was a little stressful for the SME to complete while fulfilling customer demand and continuing operations with no downtime. The cost was factored for the order management system (OMS) with an in-built inventory management system module due to the issues with the existing integrated system being used, which, once developed, had to go through rigorous testing during operational hours, which again increased the workload on staff. Overall, the SME was satisfied with the process and outcome achieved.

The experience of applying the framework with the SME highlighted the challenges inventory managers may face when attempting to implement it independently, due to the complexity of the required calculations. However, the application demonstrated the value of implementing the framework with an external consultant.

6.7 Chapter Summary

This chapter has documented the testing and evaluation of the framework in a case study organisation. It discusses the improvement in data quality and substantial cost savings at Eco Clean following the maturity assessment and the implementation of recommended actions. A critical review of the framework is also presented, identifying strengths and refinements needed to the framework. The core challenges faced in the SME are detailed in Section 6.3.1.2, and after the implementation of the IMCCT, the discrepancy rate of inaccurate inventory levels resulted in a major financial loss, recorded as £22,762.87. Applying the framework and recommended actions addressed the core challenges in improving the inventory data quality and reduced the lost inventory, resulting in cost savings of £22,237.52, bringing the monetary loss down to only £525.35 after 6 months. This, in turn, positively impacted the discrepancy rate reducing it from 10.21% to 0.53%. The following chapter concludes the research and critically reflects the research contributions.

7 Conclusion

7.1 Introduction

Chapter 7 serves as the concluding chapter of the thesis, discussing the achievement of each research objective to address the research question in *How can a socio-technical systems approach be adopted to improve inventory data quality?* The theoretical, methodological and practical research contributions to the fields of socio-technical systems and inventory management systems are outlined. The limitations of the research are discussed, and the chapter concludes by delineating potential directions for future work.

7.2 Reflection on Research Objectives

The aim of the research was to improve data quality in inventory management systems in SMEs by adopting a socio-technical approach to address challenges within IMS discussed in Chapter 2. This section critically reflects on each of the five objectives.

7.2.1 Objective 1: Develop a Model of a Socio-Technical View of Inventory Management Systems

The preliminary literature review in Chapter 1 identified that inaccurate inventory data is costly to organisations, particularly SMEs. Previous research has attempted to improve data quality through the use of technology in IMS, however, authors such as Vries (2005,2007,2013 and 2020), Muchaendepi et al. (2019), Winkelhause and Grosse (2022) and Munyaka and Yadavalli (2022), emphasise that an IMS must be viewed from both the technical and social perspectives. Chapter 1 identified a research gap: there is a lack of research on how a socio-technical approach can be adopted to improve data accuracy and address IMS challenge.

Chapter 2, Section 2.5 reviews the literature on socio-technical systems to adopt a socio-technical lens to view IMS. This facilitated the development of a model representing a socio-technical view of inventory management systems, as illustrated in Figure 9. Understanding socio-technical systems and the elements involved within this theory was essential for developing the model. Socio-technical system is defined as an abstract interaction between people, processes and technologies to deliver a required output (Chai, 2012). The construction of the model in Figure 9 directly reflects the socio-technical perspective, with the interrelation of these elements as it avoids treating these elements as independent silos, instead highlighting their interdependence. For example, changes in technology, may necessitate processes to be redesigned, people to be upskilled and organisational culture change to support technology adoption.

The proposed model (Figure 9) underscores the importance of adopting a holistic lens encompassing the established socio-technical elements, namely, Organisation, People, Process and Technology to address problems and improve inventory management systems, further extending the narrative of previous authors' work who emphasise that this perspective is necessary for efficient IMS. The holistic lens recognises that inventory management systems do not entirely involve people and technology alone, but also organisation and process, encouraging stakeholders to move beyond viewing IMS as a purely technical system. Another key insight this model provides is how misalignment between elements (such as, outdated processes paired with advanced technologies) can lead to inefficiencies within the IMS. The model of a socio-technical view of IMS forms the foundational basis for development of the framework in Chapter 5, emphasising the need for a socio-technical approach to improve data quality in inventory management systems and in turn its overall operational efficiency.

7.2.2 Objective 2: Define Challenges and Critical Success Factors (CSF) in Inventory Management Systems

A thematic literature review was conducted in Chapter 2. The literature findings resulted in a set of IMS challenges, their causal factors and critical success factors. These were subsequently categorised using a socio-technical lens against the socio-technical areas identified as organisational, people, process and technology in the model in Figure 9. The literature findings were then further analysed through a detailed mapping process, and a conceptual model was developed. The conceptual model presented in Figure 12, extends the socio-technical view of an IMS (Figure 9) by the additional mapping of IMS challenges their causal factors and CSFs.

Figure 12, the conceptual model, provides a contextual understanding of how the challenges and critical success factors have been categorised within these key socio-technical elements and their relationships. The relationships between the OPPT elements are presented in Figure 13 the matrix mapping of relationships. This further highlights the understanding of which CSFs can be applied to the identified IMS challenges and their causal factors within the OPPT areas. The conceptual model developed aims to inform the design and development of the framework in Chapter 5.

7.2.3 Objective 3: Validate Challenges and Critical Success Factors Within SME Organisations

Primary data was collected from the inventory managers of 5 SME organisations to validate the literature findings and identify any additional challenges from industry. Primary data collection was conducted using semi-structured telephone interviews to allow for a richer understanding of the data gathered. The research further explored the relevance of the literature findings in industry, providing a deeper insight and a broader view of inventory management systems. Chapter 4 presents this primary data collection and analysis conducted using soft systems methodology. Rich pictures analysis was conducted for each SME participant to further structure the problem situation within each of their respective inventory management systems, leading to the application of CATWOE analysis and development of the root definition in Section 4.4.2. The CATWOE analysis encapsulates the final combined worldview derived from the rich pictures, while also recognising the need for the transformation process leading to the defined root definition. From the data collection and the rich picture analysis, the literature findings have been validated due to the increased similarity and agreement between the IMS challenges and their causal factors and CSFs. Some of the challenges consistent across the SMEs are human error, inaccurate inventory levels, lack of processes or error-prone processes, little or no staff training, miscommunication amongst staff, culture of complacency, limited budget and resource, poor storage of inventory and space planning in the warehouse.

7.2.4 Objective 4: Develop a Framework to Improve Inventory Data Quality in Inventory Management Systems

A conceptual model was develop (Figure 24) representing the activities necessary to undertake the transformation process outlined in the root definition as ***'Improve the accuracy of inventory data',*** presented in Chapter 4, Section 4.4.3. The conceptual model informed the design and development of the framework to improve inventory data. The activities in the conceptual model were grouped into 3 sub-systems. Activities in sub-system 1 indicated the need to understand the existing IMS in the SME, activities in sub-systems 2 indicated the need to assess the existing IMS implementation and activities in sub-system 3 indicated actionable improvements needed to the IMS.

The 3 sub-systems formed the 3 stages of the framework. In stage 1 of the framework, a tool, IMCCT, was developed to address the need to first initially capture details of the organisational context in which the IMS is situation. In stage 2, a maturity model IMSMM was developed to assess the IMS. The primary data collection findings indicated that some SMEs had established policies, procedures and training for their IMS where other SMEs are less formalised. The findings obtained from both primary and secondary research relating to IMS challenges and critical success factors were used to develop the IMSMM, using De Bruin's methodology, documented in Chapter 5, Section 5.3.2.8. The IMSMM embeds the socio-technical lens by consisting of 4 dimensions: OPPT which are assessed across the 5 maturity levels (representing the inverted IMS challenges in Chapter 2, Section 2.6.1. A statistical formula was developed the Overall Maturity Index, to quantifiably measure the maturity level of the IMS, documented in Chapter 5, Section 5.3.2.11.3.

In stage 3, the critical success factors have been reshaped in the IMSMM as the recommended actions for an organisation to implement to improve the maturity of its inventory management system. The IMSMM can then be reapplied and the Overall Maturity Index recalculated to measure the impact of the recommended actions on the quality of the inventory data.

7.2.5 Objective 5: Test and Evaluate the Framework in Terms of its Effectiveness in Improving Inventory Data Quality to Improve Inventory Management Systems in SMEs

The 3-stage framework developed in Chapter 5, was tested in Chapter 6 by applying it to the selected SME organisation named Eco Clean. First, the IMCCT presented in chapter 5, Section 5.3.1 was used to gather details about the organisation's IMS and its situational context, highlighting the current state of the IMS and challenges being faced. Second, the IMSMM presented in Chapter 5, section 5.3.2.9 was implemented to assess the maturity of Eco Clean's IMS across the 4 dimensional areas: organisational, people, process and technology and the 5 maturity levels. After successfully assessing the organisation, the overall maturity index formula presented in Chapter 5, Section 5.3.2.11.3 was applied to calculate the overall maturity level percentage, giving a maturity percentage of 31%. Finally, implementing the last stage of the framework, recommended actions for improvement were given to the SME to improve the quality of their inventory data.

After 6 months of implementing the recommended actions, the maturity model was reapplied. This showed that the overall maturity level of the IMS had improved to 66%. The discrepancy rate of inventory data at Eco Clean was reduced from an initial 10.31% to 0.53% after implementing the framework. This equates to a cost saving of £22,237.52 for Eco Clean, demonstrating the effectiveness of the framework.

7.3 Discussion of Research Contributions

The research contributions are summarised and categorised as theoretical, methodological and practical contributions in the following sections.

7.3.1 Theoretical Contributions

7.3.1.1 Socio-Technical Approach

The thesis presented a theoretical contribution by adopting a socio-technical approach to improve inventory management systems and data quality. Research scholars such as Vries (2005, 2007, 2013 and 2020), Muchaendepi et al. (2019), Winkelhause & Grosse (2022) and Munyaka & Yadavalli (2022) advocate the need for a holistic socio-technical systems approach to improve inventory management. These authors postulate that an inventory management system must be viewed holistically from both the technical and social perspectives, identifying a gap in existing research regarding how a socio-technical approach can be adopted to improve inventory data and address inventory challenges. This thesis has addressed the gap by applying the socio-technical systems approach to develop a model of a socio-technical view of IMS which demonstrates the interrelation between technical and social perspectives in Figure 9. This contribution is presented as a model of a socio-technical view on IMS to understand IMS from both technical and social perspectives to improve inventory data quality and operational efficiency. Figure 9 was developed from the IMS literature; however, the model could provide a socio-technical perspective of other information systems. Figure 12 extends Figure 9 with IMS challenges, causal factors and CSFs; the relationships are then shown in Figure 13. This approach to conducting a socio-technical analysis of IMS could be replicated to structure socio-technical analysis of other information systems. The model emphasises that when implementing or changing one element within OPPT in an IMS, this would impact the other interrelated elements in the IMS, showing that the holistic synergy across all elements is needed to improve data quality. In addition, this model formed the foundational basis for the practical contribution of the 3-stage framework.

7.3.1.2 Data Quality Measures to Assess Inventory Data Quality

A second theoretical contribution is a set of data quality measures presented in Chapter 2, Section 2.7.5 specifically curated to assess inventory data quality. This contribution was driven by the research aim to improve inventory data quality as the empirical results indicate a marked improvement in inventory data accuracy following the application and testing of the 3-stage framework with the SME Eco Clean. Literature on data quality measures, facilitated the selection of pertinent measures as presented in Chapter 2, Section 2.7.5. By reviewing key data quality frameworks by Wang & Strong (1996), Dedeke (2000), Pipino et al., (2002), Chen et al., (2014) and Cai & Zhu (2015), a specific curated list of data quality measures was defined and evaluated for measuring inventory data quality in IMS. This contributes to the literature on the inventory management domain as a curated list of data quality measures specifically developed to assess inventory data quality that does not currently exist. The approach documented to define data quality measures for IMS, may be used as a guide for defining data quality measures in other domains.

7.3.2 Methodological Contribution

7.3.2.1 Application of Rich Pictures for Interview Analysis

The thesis presents a methodological contribution through the application of the soft systems methodology within the domain of inventory management systems as presented in Chapter 4 Section 4.4. The research employed rich pictures as a primary analytical tool for interpreting interview data to help facilitate a deeper understanding of the complex challenges within IMS. The rich pictures paved the way for a continued application of soft systems methodology, leading to CATWOE analysis and a root definition grounded in the overarching worldview derived from the final combined rich picture as presented in Figure 23. Moreover, the research led to the development of a conceptual model to design a system to conduct the transformation process: *A need to improve the accuracy of inventory data*. The application of the soft systems methodology in the context of inventory management systems ultimately informed the design of the 3-stage framework intended to improve data quality in inventory management systems. Following the structured approach of applying soft systems methodology not only addresses the IMS challenges but also serves as a foundational guide for future improvements in the field, especially when issues arise when advanced technologies are integrated into IMS.

7.3.3 Practical Contribution

7.3.3.1 3-Stage Framework

A framework has been developed for use by consultants working with SMEs to improve the quality of data in inventory management systems in Chapter 5 Section 5.3. This framework is presented as a practical contribution in this thesis aimed at improving inventory data quality in inventory management systems for SMEs. In stage 1, the IMCCT captures the situational context of an SME organisation's inventory management system, thereby highlighting the current state and its challenges. In stage 2, the IMSMM supports a comprehensive maturity assessment of the organisation's current inventory management system across the 4 dimensions: organisation, people, process and technology. This assessment aims to analyse and assign a maturity level percentage to the organisation's IMS. The framework incorporates a calculative statistical formula named overall maturity index to calculate the maturity level percentage presented in Chapter 5, Section 5.3.2.11. This is needed to monitor maturity improvement. This research adopts a top-down approach as the maturity model stages were initially defined and set out, leading to understanding the dimensions required to build in the OPPT socio-technical approach into the model and then calculate and determine the measurements of each of the components. In stage 3, recommended actions are then proposed to improve inventory data quality and overall performance of the IMS. The IMSMM aligns with the prescriptive definition of a maturity model as this model carries out maturity assessment and recommends improvement actions, specifically the critical success factors required to improve maturity across the levels.

The thesis demonstrates the successful application of the 3-stage framework in an SME organisation Eco Clean. Eco Clean was facing a monetary loss of just over £22,500 due to inaccurate inventory data impacting the operational performance of the IMS. Applying the framework, the company's initial maturity percentage was 3% and after implementing the recommended actions over 6 months, the maturity percentage had increased to 66%. The company reported improvements in data quality as the discrepancy rate dropped from 10.31% to 0.53%, saving the company just over £22,000 within 6 months. This can be classed as operational impact, where it analyses the direct impact of improved data quality on inventory management performance metrics such as cost reduction and inventory accuracy which have been presented through testing in Chapter 6. The benefit of the framework is highlighted within the maturity model assessment as this examines the root causes of data quality challenges within IMS.

7.4 Limitations

This section presents the limitations identified throughout the research relating to the methodological design and testing of the 3-stage framework. Highlighting limitations helps position the thesis as an adaptable contribution, encouraging subsequent research to build up on its original findings. The next section presents further work in addressing the limitations.

7.4.1 Limitation 1: Socio-Technical Approach

While a socio-technical approach has contributed positively to enhancing inventory management systems, there are several limitations to consider. Achieving the interrelatedness of social and technical elements can be difficult due to the complexity in considering multiple interdependent factors across the OPPT elements. For example, if a company prioritises cost-effective technology to be implemented, it may lead to increased workload for staff, thus increased man hours. The improved alignment between the social and technical elements can be difficult to quantify, and the analysis is reliant on qualitative methods, resulting in subjective analysis. This can impact the thesis results in a way that it may overemphasise certain elements such as technology whilst underestimating others such as people communication. The imbalance can lead to failed maturity and failure to address the root causes of poor inventory data quality. However, Figure 13 (matrix mapping) highlights the interrelationships between the OPPT elements and ensures that they are considered in joint optimisation to improve inventory data quality. In addition, the OPPT areas are given equal weighting and consideration in the IMSMM.

The socio-technical lens OPPT used in the research could be considered a limitation. A number of socio-technical frameworks were reviewed in Section 2.5.3. From these frameworks, OPPT was derived to form a practical frame with which to analyse IMS, building on the existing models of Leavitt (1965), Bostrom & Heinen (1977), Davis et al., (2014) and Chai (2012). OPPT was used to categorise the IMS challenges, causal factors and CSFs, all of which fitted within the OPPT frame. Bostrom & Heinen (1977) and Davis et al., (2014) emphasise environmental context in their models. Although environmental context was not incorporated in the OPPT frame, environmental factors were included IMCTT tool in stage 1 of the framework developed. Other aspects of models such as tasks and culture were embedded into the structure of OPPT discussed in Section 2.5.6.

7.4.2 Limitation 2: Implementation of Data Quality Measures

Contributing a curated list of specific data quality measures for use in the field of inventory management has been presented. The implementation of the data quality measures has only been conducted in this research, which impacts the credibility of the measures. Further testing of the data quality measures within other SMEs can help to strengthen and verify the accuracy and completeness of the set of measures defined.

7.4.3 Limitation 3: Application of Soft Systems Methodology

A limitation of the research is that soft systems methodology is a subjective and interpretivist approach. The application of SSM resulted in subjectivity in interpreting the data in the rich pictures, as this relied heavily on the interpretation of the interview responses. This can cause differing and varying interpretations when analysed, potentially skewing findings. In addition to this, the semi-structured interviews were only conducted with inventory managers being one stakeholder in the SMEs, and taking forward one world view from the final combined rich picture. It is acknowledged that this is not usually the conventional way to apply SSM, as there should be separate CATWOES, root definitions and conceptual models for each rich picture to address the worldviews of multiple stakeholders. However, this was the applicable approach in this research due to the repetition of the data collected and data saturation being reached.

7.4.4 Limitation 4: Scope of Testing with Organisation and Inventory Type

A limitation of the research is that the framework developed has only been tested and evaluated with one SME organisation and its applicability to larger organisations or different sectors may be limited. In addition, the IMSMM has only been developed for e-commerce SMEs with finished goods inventory. Regarding the limitation of organisation type, this research focuses on retail e-commerce SME organisations that operate online and maintain inventory in a warehouse environment for direct consumer shipping. The scope of this research does not encompass other SMEs manufacturing products or those that have physical storefronts. However, as they have similar IMS challenges such as lost/misplaced inventory, inaccurate inventory levels and poor inventory storage, potentially the model could be transferred to be applied in other SMEs. The complexity of applying the framework in an SME was noted in Section 6.6; a current limitation of the framework is that it is intended for use by consultants rather than internal staff, due to the complexity of calculations required.

7.5 Future Work

This section proposes three directions of future work: addressing the limitations, further advancing this research and other potential directions this research could take.

7.5.1 Addressing Limitations

Further work can address the limitations discussed in 7.4 by:

- Limitation 1: The limitations regarding socio-technical approach outlined in Section 7.4.1 can be addressed by using systems dynamics to further explore the relationships and feedback loops between the elements to anticipate better how changes in one element can affect other elements. Also, using iterative approaches for changes, can make it easier to adjust or realign the weighting across the STS elements for balance. The limitation of using OPPT could be addressed by using alternative socio-technical frameworks, such as Leavitt (1965) and Davis et al., (2014) to categorise the IMS challenges, causal factors and CSFs, in order to verify the results of using OPPT.
- Limitation 2: The limitation regarding the data quality measures, outlined in Section 7.4.2 can be addressed by further testing of the data quality measures to strengthen and verify the accuracy of the set measures defined. The limitations regarding data quality measures outlined in Section 7.4.2 can be addressed by undergoing iterative refinement of the model, allowing future practitioners to add, remove or adapt measures as needed ensuring the maturity model evolves with organisational and technological advancements. Additionally, flexibility could be offered within future studies to the SME to customise the measures based on their unique operational challenges, ensuring requirements are met.
- Limitation 3: The limitations regarding soft systems methodology outlined in Section 7.4.3 can be addressed by engaging additional stakeholders during the development of the rich picture/CATWOE analysis to ensure individual biases are minimised and a wider scope of worldviews are captured. Once the

stakeholders are expanded, the application of SSM can also be expanded to complete individual CATWOEs, root definitions and conceptual models to capture the different worldviews. This could help explore other worldviews and other key transformation processes related to inventory management. The themes could then be compared with the themes identified from the rich picture analysis of the interviews. The limitation of using rich pictures to analyse semi-structured interviews could be addressed by coding the interview transcripts and extracting themes.

- Limitation 4: The limitations regarding the scope of testing outlined in Section 7.4.4 can be addressed by further testing of the 3-stage framework with other SMEs. To enhance the rigour and transferability of the framework, further empirical testing across a broader more diverse range of SME contexts is needed, such as manufacturing SMEs dealing with non-finished goods inventory type regarding raw materials of work-in-progress inventory. Applying the framework within manufacturing SME warehouses can offer valuable insights into its applicability to their IMS, further validating the framework. These differing warehouse environments can present different challenges and critical success factors compared to warehouses with finished good IMS. To further develop the framework's rigour, methods including longitudinal case studies and comparative analysis across different industries can also extend the framework's validation. In terms of transferability, testing the framework within SMEs of various sizes, diverse organisational settings and technological capabilities can allow for assessment of its adaptability. This will help in identifying if any of the elements require contextual tailoring. In addition, extended testing and collecting feedback from the organisation pre and post implementation could help inform further revisions to evolve the framework in terms of its robustness, versatility and adaptability. Moving forward, involving multiple users/consultants in the application of the framework will be valuable for evaluating the framework's reproducibility and reliability. This broader engagement will also contribute to the ongoing refinement of the framework and support the establishment of industry benchmarks for maturity of inventory management systems.

- Limitation 5: The practical contribution in Section 7.3.3 can potentially open scope for use in the wider context of inventory management, where SMEs can refer back to the framework when implementing a new technology for example, AI within inventory management systems. Using the framework does not only concern the implementation of the technology but also ensures that it satisfies the needs of the other three elements organisation, people and process else it will fail to work efficiently, due to inappropriate processes/training procedures in place. This emphasises the importance of guiding the organisation when using the maturity model that when one thing is changed or implemented in one of the elements in OPPT in an IMS, it must interrelate with the other elements in OPPT to avoid individual problems arising in each element.

7.5.2 Extend Work

- Automate Framework: To address the limitation of the framework stated in Section 6.5.2 in Chapter 6 of manual tools and the risk of miscalculation due to the large calculations required, it is possible to automate the IMCCT and IMSMM. This would avoid the need to re-enter data, minimise the risk of errors in data entry and streamline the data collection conducted in stage 1 using the IMCCT, the maturity assessment data derived from applying stage 2 and the recommended actions given from the IMSMM for stage 3. In addition, automating the calculations in the overall maturity index formula will also minimise the risk of miscalculation. This is important, as in Section 6.3.2, during the application of the framework, the SME found the framework complex to use due to the formulas. The automation would help to record and visualise the changes to data quality over time, thereby demonstrating the impact of the framework in an organisation. Embedding AI functionality to support automation can also make use of predictive analytics to assess how specific critical success factors (e.g. staff training or process improvement and implementation) might impact overall maturity levels over a longer period of time. Such automation of the 3-stage framework would enhance the speed and accuracy of the implementation process and would allow potential customisation of the framework for use with a wider range of SMEs.

- Develop Practical Application Guidelines: The framework can be extended to include a set of extensive practical application guidelines on effectively implementing the 3-stage framework and correctly completing the formula calculation to calculate the overall maturity percentage index. In addition, action plan guidelines can be provided to structure the implementation of the recommended actions for the SME.
- Building Framework into an Online Tool: The framework can be built into an online system interface where SMEs can access previous maturity model assessments, re-run evaluations and benchmark against their past maturity level performances, allowing wider adoption of the framework. This in turn, facilitates a continuous improvement cycle for longevity, allowing SMEs to monitor their progress over time and revisit recommended action plans as their organisation evolves. To further enhance longevity, it is crucial that SMEs continue to apply the CSFs identified during the initial implementation of the framework. For example, staff training is identified as a CSF during the initial framework implementation; however, it should not be limited to current employees only. The training should become a part of the onboarding process for all new hires, ensuring that knowledge and practices are sustained over time. This can also include monitoring tools to ensure staff compliance over time, such as monthly and annual checks to promote longevity of the SMEs maturity improvement regarding staff training. This can be extended for all CSFs within the framework.
- Extend Application of Soft Systems Methodology: The application of SSM within inventory management systems can be extended to explore complex ill-structured problems and implications of integrating emerging technologies such as AI, IoT and blockchain into IMS. This can be done through root definitions and conceptual models to identify potential systems improving advanced technology

adoption. In addition, this contribution can incorporate SSM into ongoing inventory management system improvement initiatives, using this to further diagnose complex problematic situations and refine improvements.

7.5.3 Further Directions

Further directions this research can continue in are:

- The data quality measures defined for IMS could be further tested to become established as standardized benchmarks for measuring data quality within inventory management,
- The approach used for defining the data quality measures IMS could be applied to define data quality measures for other types of information systems, or for specific industries, to measure data quality through a socio-technical lens for improvement.
- Technologies continue to advance and introduce new challenges such as, machine learning and AI. Therefore, further work is needed to explore how emerging technologies can impact data quality in IMS. The framework can be further explored to see how it can address the new challenges.
- Future work could explore how the application of technologies such as AI and machine learning can be used to enhance the 3-stage framework using predictive analysis. This could include, for example, calculating potential measurable improvements in data quality, and the associated cost savings, of implementing recommended actions from the IMSMM.
- Exploring synergies with other existing maturity models in the field and looking into the STS elements.
- Further expanding the use of the STS approach can explore newer research domains such as how the social elements (people communication, leadership styles and team dynamics) impact technology-enabled inventory optimisation.
- Explore the applicability of the causal factors mapped to the OPPT elements within Figure 12, as being used as generic and standardized challenges in the OPPT elements within other information systems in other domains, as these challenges can be faced within other information systems.

7.6 Conclusion

The research reveals several critical insights regarding improving data quality in inventory management systems, where the thesis has asserted the importance and need of adopting a socio-technical view of inventory management systems by proposing a framework to improve data quality and operational efficiency of IMS. This addresses the research question and fulfils the research aim by demonstrating the use of a socio-technical approach to improve inventory data quality. The proposed framework consists of 3 stages: i) inventory management context capture tool (IMCCT), ii) inventory management system maturity mode (IMSMM), and iii) State and recommend improvement actions. The framework was tested and evaluated in one SME organisation, improving inventory data quality by reducing discrepancies of inaccurate inventory from 10.21% to 0.53%, resulting in significant cost savings of just over £22,000 in a 6 month time period. The overall maturity level of the IMS was assessed and improved from the initial level of 31% to 66% overall. This demonstrates how inventory data quality can be improved in SMEs by adopting a socio-technical systems approach.

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9 Appendix

9.1 Appendix (1) Interview Questions for Primary Data Collection

Question Theme	Question No.	Question
Theme 1: IMS Challenges	**1.**	Which of the following IMS challenges and their causal factors are currently experienced in your organisation? (Using list from literature).
	2.	Please explain any other IMS challenges that are currently experienced, if not mentioned initially.
	3.	Which of the OPPT categories of causal factors are responsible for the IMS challenges being caused?
	4.	Do you believe that the organisational, people, process and technology elements must work together effectively in order to aid inventory management? Why?
	5.	Which of the IMS challenges are mostly experienced or rarely experienced in your organisation? Are there others?
	6.	Please explain the reasons for the mostly experienced IMS challenges
	7.	Please rank which of the IMS challenges are high priority and low priority for your organisation.
	8.	Please rank the causal factors from high priority to low priority for your organisation.
	9.	From all of the IMS challenges and causal factors mentioned prior, what are the potential impacts on your organisation and existing inventory management?
Theme 2: Critical	**10.**	Which of the following critical success factors are currently followed in your organisation?

Success Factors	**11.**	Please explain any further critical success factors that are currently followed if not mentioned already.
	12.	Please rank the critical success factors from high priority to low priority for your organisation.
Theme 3: Type of Existing IMS	**13.**	Which inventory management system (IMS) is currently implemented?
	14.	If none/other, please explain why, what it is and how it works.
	15.	Is the existing system working well? Please explain.
Theme 4: Technology Implemented	**16.**	Do you currently use any technology to assist with managing inventory?
	17.	What existing technology is used if any and how does it work? Is it working well?
Theme 5: Overall IMS Performance and Improvements	**18.**	Can you score the importance you give to inventory management within your organisation out of 10? Explain why.
	19.	Are there any further comments in relation to inventory management within your organisation that have not been highlighted?
	20.	Based on answers given please rate the organisation in terms of inventory management performance and efficiency from a scale of 1 to 10 and explain why.
	21.	What improvements do you suggest would be needed in order to advance your inventory management efficiency and what future developments are in place if any.

9.1.1 Participant A: Summary of Interview Response

Participant A explains that the key inventory challenges faced are interrelated amongst the organisation, people, process and technology challenges impacting their inventory management. These challenges include limited resourcing, inadequate staff training measures, a prevailing culture of complacency where critical inventory discrepancies are overlooked and ineffective communication among stakeholders. Collectively, these challenges contribute to further issues such as frequent inventory inaccuracies, such as incorrect stock counts, misplacement of inventory items and data inconsistencies. These issues are further compounded by misalignment between inventory processes and the physical organisation of the warehouse leading to inefficiencies in stock storage and ultimately lost revenue. While the current use of inventory storage locations is acknowledged as generally effective, it is noted that certain products are not well accommodated, relating to the product type and its purpose. These inefficiencies adversely affect customer satisfaction as the discrepancies between system and physical level of stock mislead customers, resulting in diminished trust and damage to organisational reputation. This in turn, contributes to revenue loss. Inaccuracies in inventory result in negative impacts on the auditing report for regulatory compliance, which is a HMRC requirement. Inaccurate reporting can have serious risks to the organisation. Despite the use of barcoding technology and an automated perpetual IMS which is very beneficial, the effectiveness of the system is hindered by the users' lack of understanding, engagement and communication. The participant rates inventory management as highly important due to its direct impact on customer satisfaction and business operations. The participant emphasises that there is critical importance in integrating the organisation, people, process and technology elements to maintain efficient IMS. Some improvements suggested by the participant are enhanced training, clearer improved communication and well-structured strategic stock locations well aligned with product demand and turnover.

9.1.2 Participant B: Summary of Interview Response

Participant B highlights some key challenges affecting their inventory management practices such as frequent inaccuracies in inventory level data resulting in increased labour cost associated with having to investigate discrepancies, as well as conducting ineffective inventory auditing. Regular instances of human error in misplacing inventory items is heightened by the lack of designated storage locations. In addition to inventory inaccuracies, transaction errors are a key issue often originating from damaged goods, inconsistent supplier shipments and a lack of training for staff, resulting in further operational inefficiencies. Supplier shipments arrive frequently with quantity mismatches, and communication from suppliers is often lacking, hindering the organisation and staff's ability to resolve the discrepancies effectively and efficiently, causing minimal operational disruption. Pre-packing inventory items is a practice followed to enhance the speed of order fulfilment in the following days, however, this is undermined due to miscommunication, which hinders the accuracy of recorded inventory level data, resulting in the necessity of blind counts. Although the organisation uses Shopify's inbuilt IMS alongside manual spreadsheets, there are still instances of discrepancies when manual counts are not reflected in the system often due to human error. There is a lack of standardised processes in place for core activities in the warehouse, such as receiving goods, storing, counting, and preparing for shipment. Furthermore, limited physical storage capacity due to growing product lines poses further spatial and logistical challenges. Inventory management is rated as highly important as it directly affects audit outcomes, order fulfilment and overall business performance. Some improvements suggested include implementing barcoding technology, refining inventory processes and effective staff training to enhance inventory data accuracy and operational efficiency.

9.1.3 Participant C: Summary of Interview Response

Participant C highlights a number of operational and data related challenges in their inventory management largely attributed to human error in mis-picking inventory items resulting in higher labour cost in time spent locating items, lack of process standardisation and incorrectly processing inventory on arrival resulting in inventory level data inaccuracies. Key issues include inventory inaccuracies, lost/misplaced inventory, poor storage practices, lack of staff training in using the inhouse system efficiently. These issues significantly impact customer satisfaction and lead to high refund rates due to order fulfilment errors and misshipping. While the organisation uses an inhouse automated IMS with some machine learning algorithms, it still struggles with inaccuracies, particularly during human errors made in the inbound processes. Some improvements suggested are the tightening of the inbound receiving processes and reducing reliance on manual interventions to improve accuracy.

9.1.4 Participant D: Summary of Interview Response

Participant D highlight a range of interrelated challenges impacting their IMS. These include: limited resources and budget largely attributed to the small scale of the organisation and poor inventory planning and storage. The lack of structured storage locations, results in increased labour costs and extended time required to locate items, for order fulfilment and general inventory handling in the warehouse space. There is a lack of key processes in place contributing to operational inefficiencies, specifically discrepancies between system and physical inventory levels. People-related issues, such as poor communication and overlooking inventory errors as a result of human error, also contribute to the widespread inaccuracies. While the organisation utilises an automated IMS through the inbuilt Shopify platform, there are consistent discrepancies between the system reported inventory levels and physical inventory levels. The participant acknowledges that inventory management has been undervalued and suggests improvements such as implementing storage policies given the extensive and varied product range, and the implementation of consistent and timely inventory audits to maintain accurate inventory levels, thus reducing the frequency of product returns.

9.1.5 Participant E: Summary of Interview Response

Participant E highlight their core inventory management challenges in limited resources, technological glitches in their system and various operational efficiencies. There is an increase in labour cost due to the frequent manual checks required to ensure inventory levels are accurate as there are issues in the system automatically updating this data. Additional issues such as inventory inaccuracy, transaction errors and stockouts due to lack of timely replenishment of inventory causing poor customer experiences. There is a lack of stock-keeping unit (SKU) assignment to identify products leading to instances of inventory being inaccurately processed when received and recorded in the system. Currently there is a lack of relevant processes required such as inventory auditing and poor quality of staff training. The use of the inbuilt Shopify IMS, it is prone to lagging, glitches and complications arising from the high number of product variations, which affects both accuracy and customer satisfaction. Some improvements suggested include improved staff training, barcoding implementation and investment in a bespoke automated IMS, however it is acknowledged that these are dependent on future growth and resources.

9.2 Appendix (2) Supporting Documentation for Implementation of the Inventory Management Context Capture Tool (IMCCT)

Organisational Details	**Company Name**	Eco Clean
	Date	1st January 2024
	Department	UK Warehouse Operations
	Sales Channel	Shopify E-commerce Store
	Company Size	Small to Medium Enterprise
	Employees	5
	Multi-channel Inventory Management	Online/Retail
	Customer	B2C & B2B
Inventory Overview	**Product Range**	Eco Cleaning Products
	Product Variations	8
	SKUS Assignment	Yes
	SKUS Quantity	10
	Inventory Storage	Pallets, Overstock stored in external storage units off-site
	Total Inventory Holding Investment	£750,000 approx.
	Type of Inventory	Non-Perishable
	Nature of Inventory	Finished Goods
Organisational Overview	**Identify Workflows**	- **Receiving Inventory:** Deliveries with large shipping containers containing inventory needs to be offloaded,

		booked into inventory holding and loaded into the warehouse - **Order Fulfilment:** Orders are picked and packed, ready to be shipped to the customer - **Stock Replenishment:** When stock is required, orders are put in through products department - **Inventory Audit:** Monthly Inventory count is done of all SKUS - **Returns:** When returns are received, stock is booked back in either as sellable/non-sellable or damaged goods if damaged in transit etc
	Integrations In Place	- Shopify platform integrated into Royal Mail, using Royal Mail Click & Drop system to fulfil orders and Parcelforce. - Integrated Shopify Inventory System - Basic level spreadsheet to manage inventory levels monthly
	Integrations performance (working correctly)	- There is a backlog of orders due to orders not coming through in real-time from Shopify, this then causing a delay in fulfilling orders - Click & Drop (Royal Mail Dashboard) not easy to use: it is complex, difficult to comprehend, time-consuming to prepare orders for fulfilment, and cannot see the packing list for each order to see what needs to be packed into order, especially important for orders with more than one item.

		- Shopify Inventory module is not accurate for inventory being shipped from UK warehouse, shows discrepancies between actual shipped inventory and actual physical available inventory
	Issues with Systems	Human Errors made with data entry across all Spreadsheet Systems used above, no system wise validation in place to ensure data is correct.
	Staff Trained Effectively	7/10 Rating
	Challenges Faced	**Inaccurate transactions (Inbound/ Outbound)** • Issues when booking in receiving inventory, inventory can be mixed up when organising into warehouse. • Incorrectly documenting orders fulfilled, and inventory packed • Supplier not sending delivery organised with SKUS mixed up not separated causing mix up of inventory being booked in • Supplier not sending correct quantity per box – Box quantity is 200 units and when counting during packing

			phase it will be that there is 198 units, disrupting inventory level accuracy
		Lost/Misplaced Inventory	• Mixing up scents and product type • Misplacing inventory in other places in warehouse which impacts inventory count if not found and rectified.
		Inaccurate inventory levels (Discrepancies)	• Several discrepancies in inventory levels during inventory monthly count • If inventory is incorrect to begin with and then inventory is delivered and not noticed, this impacts the inventory levels throughout the inventory counts until it is realised when packing that the box either has more or less units than the specified box quantity
		Ineffective inventory storage (Storage assignment)	• Warehouse layout and size is small, creating issue with space and knowing where inventory is. There are no locations/zones

			for organising the inventory • Adding on 4 external storage units needed to house additional inventory. These units are in a location separate to the warehouse • Due to unforeseen growth the warehouse space has fallen short and then also stuck in a lease contract for that space
		Inaccurate Forecasting	• Inventory inaccurately forecasted, too much stock has been ordered based on warehouse space and therefore increased holding costs to house overstock in external storage unit premises.
		Inefficient inventory levels maintained (Stock-outs)	• When the inventory count is inaccurate it causes risk of stock-outs • Human error due to no validation on inventory count, did not flag that more stock was needed

			• Running out of stock unexpectedly due to no threshold trigger, process for stock replenishment notice
		Human Errors:	• Human errors frequently happening in all workflows • Mixing up SKUS and sending out incorrect stock • Not noticing boxes are missing in delivery of inventory received resulting in wrong amount of inventory being booked in (Inaccurate transactions) • Human error in order fulfilment causing inaccurate inventory levels if the wrong items are packed and shipped • Errors in inventory counting if not verified
		Additional Issues	• Staff competency is an error as it is that staff are unable to do the job correctly and

		accurately, i.e. inventory audit
	Data Synchronisation (Real Time sync)	- No
	Processes/SOPS	- **No**
	Frequency of Inbound Inventory	Quarterly with a large shipping containers worth – roughly around 1200-1500 boxes
	Replenishment Threshold	Not in place but informally 90 days worth of inventory
	Supplier Lead Times	Cannot order inventory on demand, need to wait for when next batch of finished goods are ready from supplier which depends on when orders come in for both US and UK warehouse fulfilment
	Supplier Performance	- Supplier not sending delivery organised causing mix up of inventory being booked in, container is a mix of SKUS and not well separated - Supplier not sending correct quantity per box – Box quantity is 200 units and when counting during packing phase it will be that there is 198 units, disrupting inventory level accuracy
	Warehouse Layout/Storage Space:	- Warehouse layout and size is small, creating issue with space and knowing where inventory is. There are no locations/zones for organising the inventory - Adding on 4 external storage units needed to house additional inventory - Due to unforeseen growth the warehouse space has fallen short and then stuck in a lease contract for that space# - Constantly changing the warehouse layout to suit needs in real time

		- No storage assignment in place in terms of locations/zones etc
	KPIs in place:	- KPIs only for order fulfilment workflow: Picking/Packing and Order preparation for shipping labels
	Any plans to upgrade software/Technology:	- Bespoke order management system is being rolled out to manage orders in-house easily, see dispatch notes for orders selected into batch so it is clear what is on the packing list, faster processing of shipping labels as it can take up to 2-4 hours using existing Royal Mail integrated system to Shopify - Barcoding technology for efficient inventory tracking
	Expected achievements in terms of inventory management:	- Automated Perpetual inventory system embedded to order management, to calculate automatically the inventory levels as and when inventory is received and orders are dispatched, etc. - Improved customer service, improved forecasting to avoid unnecessary additional holding costs, improved accuracy of inventory data with reduction in discrepancies in inventory levels -
	Identify Stakeholders:	- **Internal:** Inventory Manager, Warehouse crew staff, Accounts Team, Customer Service Team, Products department - **External:** Suppliers, Inbound delivery company (Container shipping from China), Outbound shipping company (Royal Mail/Parcel Force), Customers

9.3 Appendix (3) Codes for Matrix Mapping IMS Challenges, Causal Factors and Critical Success Factors

9.2.1 IMS Challenges and Causal Factors

IMS Challenge	***Code***
Inventory data inaccuracy (System & Physical)	IMS1
Stock-outs	IMS2
Forecasting Errors	MS3
Transaction errors	IMS4
Lost/misplaced stock	IMS5
Poor inventory storage	IMS6

Organisational Challenge	***Code***
Limited budget and resource	O1
Lack of attention on organisational structure, strategy, stakeholders	O2
Lack of Training	O3
Not applying clear policies	O4

People Challenge	***Code***
Miscommunication	PE1
Culture of Complacency/ Ignoring Errors	PE2
Poor Behaviour	PE3
Human error	PE4

Process Challenge	***Code***
Poor alignment within the organisational structure and existing systems	PR1
Not applying clear, well-defined processes	PR2
Lack of detailed standard operating procedures (SOPs)	PR3
Lack of integration with existing processes	PR4

Technology Challenge	***Code***
Errors with AIT technologies (RFID/Barcoding)	T1
Technology Adoption	T2
Misalignment to organisational structure	T3
Poor integration of technology within existing systems/processes	T4

9.2.2 Critical Success Factors

Organisational CSF	***Code***
Inventory Inspection	CSFO1
Just in Time	CSFO2
Economic Order Quantity	CSFO3
Quick Response	CSFO4
Staff Training	CSFO5
Inventory Auditing	CSFO6
Storage location assignment policy (Zones/locations)	CSFO7
Replenishment Policy	CSFO8

SKU Assignment	CSFO9
Design and Plan an IMS effectively	CSFO10

Process CSF	***Code***
Design and Plan an IMS effectively	CSFO10
Process integration	CSFPR1
Standard operating procedures (SOP)	CSFPR2

People CSF	***Code***
Staff training	CSFO5
Standard operating procedures (SOP)	CSFPR2
AIT (RFID/Barcoding)	CSFT1

Technology CSF	***Code***
Adopt AIT (RFID/Barcoding)	CSFT1
Dynamic Order Management System	CSFT2
Artificial Intelligence	CSFT3
Augmented Reality	CSFT4
Machine Learning	CSFT5
Robotics	CSFT6
Process Integration	CSFPR1